Agricultural Commodities as Industrial Raw Materials

J952-49

CONGRESS OF THE UNITED STATES
OFFICE OF TECHNOLOGY ASSESSMENT

Recommended Citation:

U.S. Congress, Office of Technology Assessment, *Agricultural Commodities as Industrial Raw Materials*, OTA-F-476 (Washington, DC: U.S. Government Printing Office, May 1991).

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U.S. Government Printing Office, Washington, DC 20402-9325
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Foreword

During the 1980s, American agriculture experienced widely fluctuating farm income, and many rural communities faced declining economies. These financial difficulties have led Congress to search for solutions to these problems. Because agriculture is a major industry in rural areas, diversifying agricultural markets to include industrial uses in addition to traditional food and feed markets, is viewed as a means of strengthening agricultural and rural economies. Additional concerns that could potentially be addressed by using agricultural commodities as industrial raw material sources include environmental pollution and U.S. industrial vulnerability to petroleum and strategic material supply shocks.

Congress requested the Office of Technology Assessment to assess the use of agricultural commodities as industrial raw materials. This report examines potential new crops and traditional crops for industrial uses including replacements for petroleum and imported strategic materials; replacements for imported newsprint, wood rosins, rubbers, and oils; and degradable plastics. The analysis includes an assessment of the technical, institutional, economic, and policy constraints to the development of crops for these uses; discussion of programs available for assistance; and examination of the potential implications of using agricultural commodities as industrial raw materials.

This report finds that, in the absence of additional and more comprehensive policies, developing industrial uses for agricultural commodities alone is unlikely to revitalize rural economies and solve the problems of American agriculture. However, it is possible to provide domestic sources for many imported industrial materials, some of which are considered to be of strategic importance, and potentially to replace selected petroleum-derived chemicals. And, some industrial uses of agricultural commodities offer potential to decrease certain types of environmental pollution.

This report was requested as part of a larger study examining emerging agricultural technologies and related issues for the 1990s. The study was requested by the Senate Committee on Agriculture, Nutrition, and Forestry, the House Committee on Agriculture, and the House Committee on Government Operations. Two reports issued from this study are: *Agricultural Research and Technology Transfer Policies for the 1990s* and *U.S. Dairy Industry at a Crossroad: Biotechnology and Policy Choices*. One additional report is in progress. Findings of this report are relevant to specific legislation regarding agricultural research and technology transfer that was debated for the 1990 Farm Bill. The information contained in this report was made available to Congress for that debate.

In the course of preparing this report, OTA drew on the experience of many individuals. In particular, we appreciate the assistance of all of the workshop participants. We would also like to acknowledge the critiques of the reviewers who helped to ensure the accuracy of our analysis. It should be understood, however, that OTA assumes full responsibility for the content of this report.

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Chapter 1

Summary

Interest in diversifying agriculture has been increasing, due to changes affecting the industry. Widely fluctuating farm incomes ($38 billion in 1979, $13 billion in 1983, and $34 billion in 1986)[1] have led the agricultural community to seek new, high-growth markets. Erosion of the economic base of rural communities, and the pressures faced by small farms, have intensified the search for new economic activities. Soil erosion, agrichemical groundwater contamination, and other environmental problems resulting from modern agriculture have spurred interest in developing new crops that may be better suited to some geoclimatic regions than current crops and that provide farmers with more crop rotation alternatives. Policymakers dealing with government budget constraints are seeking ways to reduce surpluses and commodity support payments. Concerns about the long-term supply of petroleum have led to an interest in the potential of renewable resources, including agricultural commodities, to replace petroleum derived products. Development of new industrial crops and uses of traditional crops is viewed as at least a partial solution to these pressing problems.

Agricultural commodities traditionally are used for food or livestock feed, but potentially could provide chemicals for use in a wide range of industrial applications. Vegetable oils and plant resins can be used as components of lubricants, paints, detergents, and plastics among others. Starch can be used to produce biopolymers, or as a food source for bacteria that produce commodity chemicals. New fibers can replace wood pulp in a variety of paper and paperboard products. Crops that are traditionally grown in the United States are used in limited quantities for industrial purposes. Additionally, the United States imports selected agricultural products for industrial use. Uses of traditional crops can be expanded, and new crops can be adapted to U.S. production to provide many of these products.

Many constraints must be overcome before agricultural commodities will become a primary source of industrial raw materials. Technical constraints include agronomic problems such as seed shattering and dormancy, low yields, insect pollination, and photoperiodism among others. For some new crops, the lack of germplasm may constrain research efforts. Utilization research is needed before chemicals from crops can be used industrially. And, the efficiency and productivity of new industrial use processes must be increased. With sufficient research funding and effort, it is likely that many of these technical constraints can be overcome.

Economic, rather than technical constraints, will likely impede the development of new industrial crops and uses most severely. New industrial uses must be acceptable to manufacturers and the products produced accepted by consumers. For example, several proposed new crops produce chemicals that are already being used in industrial processes. The current sources of these chemicals are petroleum and agricultural imports. To be acceptable to manufacturers, chemicals derived from new crops must be competitive with current sources in terms of price, quality, and performance. Similarly, many potential new uses for agricultural commodities will compete with products already in use.

New crops must also be acceptable to farmers. Adoption of new crops by farmers will depend largely on their profitability relative to crops the farmer can grow now. Profitability can be increased if multiple uses for new crops can be found and developed; many of the chemicals that could be derived from new crops currently have limited demand.

Research to develop industrial uses of agricultural commodities is diverse and takes place in government laboratories, universities, and the private sector. Several Federal programs exist that can facilitate the development of new industrial crops and uses, and funding for research and development activities has been an estimated $10 to $15 million annually. Federal funding has primarily supported research on the new crops guayule, kenaf, *Crambe*, and rapeseed, and on new uses of cornstarch (e.g., for ethanol production). Federal funding sources include primarily the Department of Defense, the National Science Foundation, the Department of Energy, and the Department of Agriculture. Proponents of developing agricultural commodities as industrial raw materials perceive these programs as being inadequate, and have called for new initiatives. Legislation introduced in the 100th and 101st Congresses, and passed in the 101st Congress, authorizes funding for research, development, and commercialization of new crops and new uses of traditional crops. Goals of the legislation include diversifying and stabilizing the agricultural sector, enhancing rural development, and increasing family-farm incomes. Additionally, proponents hope that the new crops and uses of traditional crops will be more environmentally benign than current crops, will improve the U.S. balance of trade, and will decrease Federal agricultural payments. However, several questions remain concerning the appropriate goals of new crop and use development, and the best institutional arrangements for achieving those goals.

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[1] These numbers represent net income from farming in 1982-84 dollars. Net income includes cash receipts from farm marketings and government payments, plus non-money and other farm income minus production expenses. Off-farm income is not included. Source: USDA Agricultural Statistics, 1988.

Major Findings

As with all new technologies, development, commercialization and adoption of new industrial crops and uses of traditional crops will have many impacts, some positive and some negative. At issue are questions such as:

- What benefits can realistically be achieved?
- What adverse impacts can be expected?
- What constraints (policy, institutional, social, economic, environmental, or technical) impede development?
- How can policy and institutions be structured to be efficient, cost-effective, maximize benefits, and minimize adverse impacts?

Chemicals derived from agricultural commodities have a potentially broad range of industrial applications, and many are technically promising. Technical feasibility, however, will not be sufficient for widespread adoption. Chemicals derived from agricultural commodities must be less expensive than those currently available, or provide a superior product in terms of quality, performance, supply availability, or environmental benefits among other criteria. Environmental regulations could have a significant impact on the development of new industrial crops and uses of traditional crops. And economic competitiveness will hinge on the ability to develop markets for processing byproducts. OTA concludes that:

- Development of new industrial crops and uses of traditional crops offers future flexibility to respond to changing political, economic, and environmental conditions in supplying industrial materials, although currently, many are not economically competitive with alternatives.
- Commercialization potential will be enhanced if research and development efforts take a systemic approach and are directed toward creating a package of products rather than a single product.

It takes many years to develop a new use or crop, and during that time political, economic, and environmental conditions could change. Research and development of new products and processes lays the groundwork necessary to respond quickly and effectively to these changing conditions. It is unlikely that individual firms will be willing to make large investments to develop substitutes for future hypothetical changes. Arguments can be made, however, that this may constitute a legitimate public-sector investment.

The economic competitiveness of using agricultural commodities for industrial uses hinges on the ability to develop markets for the primary product and any processing byproducts. For example, the cost of using corn for ethanol production depends on the cost of the corn minus any credits received for the gluten meal, distillers grains, and oil produced as byproducts. The industrial market share of vegetable oil fatty acids will depend on the fatty acids being competitive with petroleum-derived products as well as the extent to which the glycerin byproduct can compete with petroleum-derived glycerin, and markets can be found for the meal. Thus, development strategies must consider developing a package of products, rather than a single use only.

Research Needs

At the present time, the information that is needed to make a thorough assessment of the market potential, and socioeconomic and environmental impacts of developing new technologies using agricultural commodities is seriously lacking. A clear need exists for research not only to help develop new crops and uses, but also to help policymakers evaluate the potential benefits to be gained from these new technologies. Rigorous analysis of the potential magnitude of impacts, who gains and loses and by how much, and whether benefits can be achieved in a cost-effective manner is needed. In particular:

- Chemical, physical, and biological research is needed to improve the efficiency of obtaining chemicals from agricultural crops, to improve the efficiency of their use in industrial processes, to develop new products, and to improve the agronomic characteristics of agricultural crops.
- Market research is needed to identify commercial opportunities and constraints.
- Social science research is needed to evaluate the socioeconomic impacts that will result from technical change.
- Environmental research is needed to evaluate the potential positive and negative environmental impacts of developing new industrial crops and uses of traditional crops.
- Germplasm collection and germplasm storage and maintenance research is needed.

Many technical and agronomic improvements are still needed before new industrial crops and uses of traditional crops will be commercially viable. Lack of germplasm may constrain research efforts, particularly for new crops. Research to improve technical feasibility can improve the economic competitiveness of using chemicals derived from agricultural commodities, but it cannot be assumed, that in all cases, these improvements will be sufficient to guarantee success. Market needs must be identified and products developed that can economically meet those needs. Developing a product first, and then trying to find a market, is not the most effective approach. Identifying market needs will require an understanding of the short and long term trends in input supply, product demand, and structural change occuring within the industries involved. Development of new industrial crops and uses of traditional crops, like any new technology, will benefit some, and harm others. These trade-offs have not been analyzed adequately.

Potential Impacts of Using Agricultural Commodities as Industrial Raw Materials

Due to the lack of studies needed to evaluate the potential market and impacts of new industrial crops and uses of traditional crops, definitive statements concerning the potential benefits and cost-effectiveness of development cannot be made at the present time. Of the few available studies, most examine expanding ethanol production from corn, an industrial use of a traditional crop. While they do not directly analyze new industrial crops or uses of traditional crops, some studies are available that examine issues pertinent to the development of these new technologies. For example, research evaluating factors that cause instability in the agricultural sector and new technology adoption by farmers have been conducted, and can be used to analyze the potential impact on small farms and agricultural stability of new crops and uses. Additionally, studies on rural industrialization and changes in rural employment during the 1970s, when demand for agricultural commodities grew rapidly, can provide insights on potential rural employment impacts of expanding industrial uses of some agricultural commodities. These studies raise serious questions about the potential benefits and costs of new industrial crop and use development. Based on these studies, OTA concludes:

- Evaluation of rural employment in the 1970s and 1980s suggests that the rural employment impacts of new industrial crops and uses may be modest, and that most employment increases are likely to be in metropolitan rather than rural communities. The rural counties likely to be most affected are the fewer than 25 percent that are agriculturally dependent.
- Development of new industrial crops and uses of traditional crops, without additional policy measures, is likely to have a modest impact on the income of small-commercial and part-time farmers.
- New industrial crops and uses of traditional crops could potentially provide a domestic source of strategic and essential chemical compounds that are currently imported or derived from petroleum, however, many are not currently economically competitive with these sources.
- New industrial crops and uses of traditional crops can potentially have positive and negative environmental impacts.
- It is not clear that the development of new industrial crops and uses of traditional crops will significantly rectify factors that cause instability in agriculture, and thus stabilize the agricultural sector.

- It cannot be unambiguously stated that new industrial crops and uses of traditional crops will improve the U.S. trade deficit or significantly reduce Federal expenditures.
- Development of new industrial crops and uses of traditional crops could potentially compete for some of the markets of currently produced crops.
- Development of new industrial crops and uses of traditional crops has the potential to provide diversification alternatives and new agricultural markets.
- Premature attempts to commercialize the new industrial crops and uses of traditional crops may delay any further efforts to develop these uses.

Rural development, small farm survival, and agricultural stabilization will require comprehensive approaches. Development and commercialization of new industrial crops and uses of traditional crops can be one component of these approaches but, by itself, will not be sufficient to accomplish these goals. Information needed to assess the cost-effectiveness of new crop and use commercialization relative to other strategies is not available. Historically, however, social rates of return to agricultural research investment have been high.

Rural Employment

The structure of rural communities has changed significantly over the last 40 years; rural economies have diversified and are now strongly linked to the U.S. national economy and to global events. Linkages between agriculture and rural economies has eroded over this time, and rural development policy and agricultural policy are no longer synonymous. Development and commercialization of new industrial crops and uses, while containing industrial elements, is still, however, essentially an agricultural policy.

Proponents of new industrial crop and use development feel that these efforts will increase rural employment through community multiplier effects resulting from enhanced farm income and increased agricultural input use, and by creating new jobs resulting from the full-utilization, expansion, or construction of processing and manufacturing facilities that use agricultural commodities. The second half of the 1970s was characterized by rapid expansion of agricultural production and provides insights on potential employment impacts of increased industrial demand for agricultural commodities. Over this period, rural employment in agriculturally related industries increased slowly. In general, the agriculture processing industry is not labor-intensive, has excess capacity, and has increased productivity even as employment levels dropped. Agriculturally dependent counties (less than 25 percent of all rural counties) are those that will be most significantly affected.

Agricultural commodity processing facilities are not always located near the site of production of the commodity. Indeed, at least half of all jobs in agriculturally related industries are located in metropolitan, rather than rural, areas. Need and availability of skilled workers, institutions that provide managerial and vocational education, natural resources, and appropriate infrastructure including transportation and information technologies will be major determinants of manufacturing or processing plant location. These needs will generally favor metropolitan areas, rather than rural communities. However, special storage, processing, or transportation requirements may make construction or expansion of processing facilities in crop production regions desirable.

Aid to Small Farms

One goal of using agricultural commodities as industrial raw materials is to provide higher income alternatives to small farms. However, in many cases, the problems faced by small farms are not the lack of available technologies, rather it is the inability of their operators to take advantage of new technologies. Small farm operators may lack financial resources or the management skills needed. Adoption of new technologies is risky, and operators of small farms may not be willing or able to accept the added risk. Gains from new technologies accrue primarily to early adopters; it is unlikely that small farms will be the earliest adopters of many of the new technologies.

Small, part-time farmers receive the majority of their income from off-farm activities; changes in the market prices of commodities may not significantly increase their total income. For those that participate, agricultural commodity programs buffer the impacts of price changes for many traditional crops. These factors limit the income effects for small farms that might result from the development of new uses for traditional crops. Commercialization of new industrial crops and uses of traditional crops—

combined with programs to teach operators of small farms new management skills, help them obtain financing, and provide insurance for the additional risks assumed—may help to enhance small farm incomes. Without these additional programs, commercialization of new industrial crops and uses of traditional crops may not significantly enhance the income of small farms.

Strategic Materials and Petroleum Replacement Potential

Several of the new crops could provide the United States with a domestic supply of materials that have strategic and essential industrial uses. The United States currently imports agricultural commodities or uses petroleum derived chemicals for these purposes. Materials of strategic importance are stored in a strategic material reserve. Domestic production may be desirable for security reasons.

Agricultural commodities used to produce fuel and primary feedstock chemicals have the potential to replace the largest quantities of petroleum imports. Other markets, such as some of the uses for vegetable oils, are much smaller. It is technically feasible to use agriculturally derived chemicals as fuel and industrial feedstocks, but because the petroleum industry is a highly integrated and flexible system that can change the type, amount, and price of chemicals it produces to respond to market conditions, the use of agriculturally derived chemicals is not currently economically competitive in most of these markets.

Large-scale development of agricultural commodities for fuel and chemical uses will likely result in major changes in land-use patterns, accompanied by environmental impacts, as well as impacts on food prices. Additionally, petroleum-derived energy is used to produce agricultural commodities and convert chemicals derived from these commodities; this usage must be substracted to determine petroleum replacement potential.

Environmental Impacts

New industrial crops and uses can potentially have positive and negative environmental impacts. New crops offer additional options for crop rotation, soil erosion control, and other conservation efforts. However, farm commodity programs that discourage crop rotations, and conservation programs that prohibit harvesting of crops grown on some land may inhibit the use of these new crops. Changes in the 1990 Farm Bill may correct some of these constraints. Several new crops are better adapted to semiarid environments and require less irrigation than many crops currently grown in those areas. Potential positive environmental impacts could result from new uses of traditional crops such as road de-icers, and coal desulfurization. Alternative fuels could potentially improve air quality. Currently, these uses are not economically competitive, in part because the prices of alternatives do not reflect the true cost of adverse environmental impacts.

Many new crops are not native to the United States and the introduction of foreign species can sometimes lead to unexpected problems. Some newly introduced crops (i.e., Johnson grass) have become serious weeds, while others could potentially serve as a repository for crop diseases. Many crops may be genetically engineered, and the environmental release of these crops raises many environmental questions. Additionally, large changes in land use patterns and inputs could have far-reaching environmental impacts, not all of which may be positive.

Agricultural Stability

Instability in the U.S. agricultural industry results primarily from weather variation, market imperfections (i.e., lack of complete markets and asymetric information between buyers and sellers) and macroeconomic policy (primarily U.S. Government deficits and money supply policies). Globalization of the goods and financial markets magnifies these impacts.

The development of new industrial crops and uses of traditional crops does not address macroeconomic policies. In addition to the agricultural sector itself, many industries that will use new crops to produce new products are also highly sensitive to macroeconomic conditions. Diversifying into these new markets will not shelter the agriculture sector from macroeconomic impacts. Diversification of crop production can moderate adverse weather impacts, but if monoculture increases to meet the demands for new uses of traditional crops, the opposite effect could occur. Development of new marketing institutions, or greater use of available market instruments that reduce risks (i.e., futures markets, forward contracts, crop insurance, etc.) could improve agricultural stability. Improvements in market institutions and reduction of U.S. deficits are needed to help stabilize agriculture.

Diversification

Technological approaches can offer new market and production opportunities and provide flexibility to respond to changing economic, political, and environmental conditions. Many of the new industrial crops and uses of traditional crops are not economically and/or technically competitive in their current state of development and under current economic conditions, but conditions can change. It takes many years of sustained research to develop a new crop or a new use. Providing research and development funding and encouraging public sector/private sector interaction now, can greatly reduce the lead time necessary should conditions change and commercialization becomes attractive.

Premature Commercialization

Premature commercialization attempts could potentially halt, or at least delay, the development of a new industrial crop or use. As an example, public disillusionment with degradable plastics has resulted in lawsuits against companies making degradable plastic products, and some demands for the elimination of publicly supported research for these products. Legislation passed in the 101st Congress authorizes funding to encourage rapid commercialization of industrial uses of agricultural commodities.

Additional Potential Impacts

Current domestic uses for many of the chemicals derived from new crops are limited, and production of these crops to meet this demand may not have a large impact on U.S. agriculture in the aggregate. Concentrated production in a localized region could possibly be significant for that area. Simultaneous development of several new crops and uses will have larger impacts. Development of new uses for a currently grown crop that raises the price of the crop may have a more significant impact due to the volumes involved and the impact on commodity support payments. The potential for domestic and export market expansion can only be discussed in crude terms. Good market studies are needed, but unfortunately are lacking.

Impacts of most new crops and uses on Federal farm expenditures, surpluses, and the trade deficit cannot be determined at the present time. Improved information about market demand and profitability is needed to make those assessments. Surpluses and commodity payment impacts of new crops will depend on which currently grown crops are replaced by new crops. For example, corn is a surplus crop and, in 1988, nearly 60 percent of the crop was enrolled in the commodity support program. On the other hand, production of oats in the United States is in deficit and, in 1988, less than 1 percent of the crop was enrolled in commodity programs. Shifting acreage from corn production to new crop production may result in decreased corn surpluses and reduced Federal commodity expenditures. However, shifting acreage from the production of oats to new crops will not significantly affect surpluses and commodity payments.

For new uses of traditional crops, impacts on Federal expenditures will depend in part on whether the new use must be subsidized to be economically competitive. Ethanol is an example. Excise tax exemptions potentially could offset most, or all, commodity program savings. The impacts of new industrial crops and uses of traditional crops on the trade deficit are similarly ambiguous.

Development and adoption of new crops or new uses could result in some income reallocation. Many new crops and uses have high protein meal as a byproduct. Significant levels of adoption could potentially displace soybean meal in some livestock feed markets, and lower soybean prices. Byproducts from ethanol production will also put pressure on soybean prices as they compete in the same oil and livestock feed markets. Soybean farmers in the Southeast and Delta regions are most likely to be adversely affected, while corn farmers in the Midwest will be most positively affected.

Many new crops have the potential to substitute for, and at least partially replace, major agricultural exports of developing countries, some of which are of strategic importance to the United States. Substitutes for coconut oil, palm oil, and rubber are examples. Attempts to increase exports of corn gluten meal, which is a byproduct of ethanol production, may meet with resistance from the European Community. An improved understanding of potential international ramifications is needed.

Policy Issues

The lack of research to evaluate market potential and impact of new industrial crop and use development, as well as the technical constraints that still exist suggest several research needs as have already been discussed. What can be clearly deduced, however, is that commercialization prospects will be improved if a systems approach is taken, and if a package of technologies and products is developed with markets identified for all products.

Because legislation has the goal of developing new products, research will need to be more focused and directed than would be the case if the goal were to improve scientific knowledge. To improve the science base, it is reasonable to focus research funding on proposals that are the most scientifically sound and interesting regardless of the topic area. However, taking this approach to the development of new products is likely to exclude research needed for commercialization. Research results are unpredictable, so some undirected research is still needed. However, most of the research should be focused on overcoming as many obstacles to commercialization as possible.

While disciplinary research in the physical, biological, and social sciences is needed, multidisciplinary research will be essential. Because of the diffuse geographical nature of agricultural production and industry distribution, multiregional research may be needed in some cases. A European Economic Community research program (ECLAIR —European Collaborative Linkage of Agriculture and Industry Through Research), established to develop industrial uses of agricultural commodities, recognizes these needs and explicitly requires multidisciplinary research and the active participation of at least two countries in all projects. U.S. legislation does not require multidisciplinary or multiregional research although this type of research could qualify for funding. Ample evidence exists, however, that if it is not required, it is unlikely to occur.

There must be a mechanism to set research priorities. Development of many new crops and uses will be expensive. As an example, between 1978 and 1989, Federal expenditures for guayule development have been nearly $50 million. Estimated funding requirements through 1996 are an additional $38 million. Funding is limited, and it must be decided how to best allocate those resources. A mechanism is needed to assess the benefits, negative impacts, timeframe and development costs of new technologies, and then to allocate resources to those that are most promising.

To achieve technical change, policies must address constraints and opportunities in the research and development, commercialization, and adoption stages. A wide variety of options and flexibility in their selection will be of paramount importance. Funding for research, public sector/private sector cooperative agreements, and commercialization is important, but not the only issue. Finding ways to help industry minimize the search costs of acquiring information, providing technical assistance and training to aid the adoption of new technologies, and agricultural extension programs to aid farmer adoption of new crops also are important.

Additional questions exist as to the most appropriate institutional structure for administering policies and developing new technologies using agricultural commodities: is the establishment of a new institution (within but independent of USDA) necessary, or might a reassessment of how USDA sets priorities and allocates resources for research and development of agricultural technologies achieve similar ends? An underlying force driving the call for new legislation to help develop new industrial crops and uses of traditional crops is the perceived lack of responsiveness of the U.S. Department of Agriculture. Proponents of new industrial crop and use commercialization feel that USDA provides inadequate research funding and insufficient interaction with the private sector. Similar frustrations are often voiced with respect to other agricultural technologies. In terms of research, development, and commercialization, new industrial crops and uses of traditional crops are no different from other agricultural technologies. Thus a critical issue is whether it is best to establish corporations to commercialize each technology type, or to address fundamental problems that exist within USDA.

On the one hand, a new institution could focus its full attention on new crops and uses and serve as a central organization that is easily recognized and accessible to those interested in commercializing new agricultural technologies. On the other hand, a new institution may be isolated and unable to coordinate with other agencies in USDA, develop its own constituency (making it difficult to terminate) and may develop goals that are in conflict with those of the USDA. Historically, the establishment of new institutions within USDA has been a serious problem, and has hampered attempts to coordinate policies and programs. Addressing fundamental problems with USDA priority setting and research resource allocation mechanisms will improve the research and development prospects of a wide range of agricultural technologies, not just new industrial crops and uses of traditional crops.

Policy Options

Technical change (i.e., changes in an economy's mix of products and processes) involves three stages: research and development (development of ideas or models), commercialization (commercial development and marketing), and technology adoption.[2] To successfully achieve technical change, policies are needed that help overcome constraints in all three phases. Presently, science policy focuses mainly on research, development, and commercialization. Issues of adoption have been given little attention. OTA has identified several potential policy options to help facilitate the development of new industrial crops and uses of traditional crops.

Research and Development

Public-sector research for industrial new crops and uses requires a sustained allocation of personnel and funding. Emphasis should be placed on interdisciplinary research. Interregional projects will be needed in some cases. Research needed to develop new industrial products must include marketing, economic, and social welfare analysis as well as biological and chemical research. Potential environmental impacts must be evaluated; this is particularly pertinent for genetically engineered crops, and for new crop introductions that involve expanding the range of indigenous species, or the planned introduction of non-indigenous species to the United States. Research to develop new industrial crops and uses could be constrained by the lack of appropriate germplasm needed to improve agronomic characteristics and to screen for useful, and as yet unidentified, chemicals. Collection and research to improve maintenance and storage of germplasm is needed.

Technology Transfer and Commercialization

The Technology Transfer Act of 1986 and the National Competitiveness Technology Transfer Act of 1989 removed most major barriers to private-sector cooperative agreements with Federal laboratories. There is still a need to provide adequate funding for these activities and to provide professional incentives for public sector participation. In addition to cooperative agreements, public sector/private sector interaction can be stimulated by other means as well. Other policies might include loans and use of specialized public-sector facilities and equipment. Programs such as the Small Business Innovation Research Program can help the private and public sectors share the cost of risky research.

Federally supported research is conducted in thousands of Federal, university, and non-profit laboratories. Learning about and assessing pertinent information is still a major problem for private firms interested in utilizing publicly funded research. Holding conferences that showcase Federal laboratory research and improving databases describing federally funded research are two methods of providing information to private firms.

Adoption

Many new products and technologies developed and marketed may be inputs or processes needed to produce other products. In these cases, the adoption of these new technologies by firms within an industry will be needed. As with technology transfer, gathering information about new technologies is costly. Many firms may be small or lack an in-house research capacity, and may need assistance before using these new technologies. There may be a need for technical extension programs. Likewise, agricultural extension as well as commodity programs will play major roles in determining the extent and speed of farm adoption of new crops.

Legislation Passed

OTA has identified the need for policies to address the research and development of new industrial crops and uses of traditional crops, technology transfer and commercialization issues, and the issues of the adoption of new technologies. These options are discussed in chapter 6, and were made available to the House and Senate Agricultural Committees during their debate on the Farm Bill. In the fall of 1990, the 101st Congress passed the Food, Agriculture, Conservation, and Trade Act of 1990 (1990 Farm Bill). The issues of industrial crops and uses of traditional crops, USDA research priorities, and agricultural commodity programs that affect farmer adoption of new crops were debated and legislation passed as part of the Farm Bill. Following is a summary of the main legislation that affects the development and commercialization of new industrial crops and uses of traditional crops.

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[2] For the purposes of this report, commercialization is being defined as the actual production and sale of products. The process leading to that stage is referred to as research and development.

- The Alternative Agricultural Research and Commercialization Act was passed to establish a Center for these actitivities. Establishment of Regional Centers to assist commercialization was also authorized.
- Commodity programs were changed to allow for greater planting flexibility. A Triple Base Option was adopted.
- An Agricultural Science and Technology Review Board was created within USDA to review current and emerging agricultural research issues and to provide a technical assessment of new technologies.

Alternative Agricultural Research and Commercialization Act

This Act creates an Alternative Agricultural Research and Commercialization Center, an independent entity located within USDA. The Act also authorizes the establishment of two to six regional centers to assist in commercializing new industrial crops and uses of traditional crops. Heavy emphasis is placed on commercialization funding. Funding is also provided for research and development, and public sector/private sector cooperative research agreements.

Because of incompatible timing of the Farm Bill and Appropriations legislation, funding for the new Alternative Agricultural Research and Commercialization Center was not provided. Instead, the Critical Agricultural Materials Act was reauthorized through FY 1995 and funding appropriated for the Office of Critical Materials. Congress will likely consider funding of the Center in 1991.

Commodity Programs

Congress passed a Triple Base Option plan, to begin in 1992. Under the plan, the base acreage for program crops (wheat, corn, grain sorghum, oats, barley, upland cotton, or rice) is established. Acreage Reduction Programs (ARP) will remove a percentage of that acreage from production. Fifteen percent of base acreage is excluded from receiving commodity payments and can be planted to program crops or other designated crops (i.e., oilseeds and industrial or experimental crops designated by the Secretary of Agriculture). An additional 10 percent of acreage can be planted to non-program crops without the loss of program base acreage. These new flexibility provisions, and removal of acreage that is eligible for support payments will help to remove some of the disincentives to the planting of new industrial crops. Additionally, target prices were nominally frozen at 1990 levels, but changes in the way deficiency payments are calculated may effectively reduce price levels.

Agricultural Science and Technology Review Board

This board consists of 11 representatives from ARS, CSRS, Extension Service, Land Grant Universities, private foundations, and firms involved in agricultural research, technology transfer, or education. The purpose of the Board is to provide a technology assessment of current and emerging public and private agricultural research and technology transfer initiatives and to determine their potential to foster a variety of environmental, social, economic, and scientific goals. The report of the Board is to include an assessment of research activities conducted, and recommendations on how such research could best be directed to achieve desired goals. Establishment of this Board is an attempt to address some of the fundamental problems existing in the USDA research and extension system.

The legislation enacted addresses some research, development, technology transfer, and farm adoption issues relevant to new crops and new uses of industrial crops. Congress may wish, in the future, to explore further other issues that could enhance the development of these crops and uses. These issues include germplasm collection and maintenance, the role of technical assistance and technical extension programs, improving equity markets in rural communities, and establishing programs to help small farm operators adopt and utilize new technologies.

Conclusions

Using agricultural commodities as industrial raw materials will not provide a quick and painless fix for the problems of agriculture and rural economies. They can provide future flexibility to respond to changing needs and economic environments, but many technical, economic, and policy constraints must be overcome. Many of the new industrial crops and uses of traditional crops are still in relatively early stages of development. Several years of research and development will be necessary before their commercialization will be feasible. The lack of marketing strategies and research to assess the impacts of new technologies complicates decisions on research priorities and appropriate policies and institutions needed to achieve success. Potential impacts on income reallocation and the environment, as well as regional effects need further study before large-scale funding for commercialization is required. Successful commercialization will require not just funding assistance, but a systemic policy that articulates clear and achievable goals and provides the instruments needed to reach those goals.

An encompassing research and development strategy is needed and must be designed to meet market needs; hence a strategic, multidisciplinary, multiregional approach should be taken with both public and private sector involvement. Changes in agricultural commodity programs, in addition to those already made, may still be needed to remove disincentives to the adoption of many new crops. Because of research information still needed, and the time still required to develop many of the new crops and products, a two-step approach to commercialization might be useful. The European community is taking this approach by first establishing a precommercialization program to determine feasibility, and then following up with a later program to encourage commercialization. The U.S. Small Business Innovation Research Program also takes a multistage approach to the commercialization of new technologies.

In the United States, initial primary emphasis could be given to the basic, applied and precommercialization research needed to develop new crops and uses. A high priority should be an early technology assessment of products and processes to analyze potential markets, socioeconomic and environmental impacts, technical constraints, and areas of research needed to address these issues fully. The establishment of the USDA Science and Technology Review Board should improve the prospects for this type of assessment. The technology assessment would lay the groundwork for development, and provide the information needed to make intelligent decisions about commercialization priorities, possible impacts of new technologies, and further research or policy actions needed.

Interdisciplinary, and in appropriate cases, multiregional research should be given the highest funding priority. This could include: chemical, physical, and biological research needed to improve production yields and chemical conversion efficiencies, and to establish quality control and performance standards; agronomic research to improve suitability for agricultural production; germplasm collection and maintenance research; and social science and environmental research. Technology transfer issues should also be addressed. These issues include funding for cooperative agreements, database management, and Federal laboratory-industrial conferences.

Once information is available to identify market potential and technical, economic, and institutional constraints, the second step to commercialization can be made. A strategic plan can be developed to commercialize the most promising technologies. Financial aid for commercialization and the role of regulations may need to be considered. Industrial adoption and diffusion of new processes may require additional technical assistance and technical extension programs. For new industrial crops and uses, additional changes may be needed in agricultural commodity programs.

Because many new industrial crops and uses of traditional crops are still in the early stages of development, there is time for a thorough analysis of the actual potential of these new products, the constraints to commercialization, and the potential impacts of development. This information, once it is available, will permit the design of appropriate policy and institutions needed to achieve the benefits that can be gained from using agricultural commodities as industrial raw materials.

Chapter 2
Introduction

Industrial Uses of Agricultural Commodities in the United States

Currently, the United States uses chemicals derived from agricultural commodities for a wide range of industrial applications. Industrial uses, however, represent only a small percent of total U.S. production of agricultural commodities. As an example, industrial uses of vegetable oils use no more than 2 percent of the total U.S. production of vegetable oils (12). Industrially useful compounds derived from renewable resources, including agricultural commodities include:

1. oils and waxes;
2. resins, gums, rubbers, and latexes;
3. fibers;
4. starches and sugars; and
5. proteins.

Oils and Waxes

Lipids (fats and oils) are water-insoluble compounds found in the cells of plants and animals. They serve as structural components of membranes, and as metabolic fuel. Lipids are composed of triglycerides that can be decomposed into fatty acids and glycerol, a chemical that is used in soaps and detergents. Fatty acids consist of carbon chains. The length of the chain, the number of double bonds between the carbons of the chain (the degree of unsaturation), and the type of reactive groups attached (e.g., epoxy and hydroxy groups), determine the characteristics and uses of the various fatty acids. Longer chain (12 or more carbons) fatty acids are used most frequently in detergents. Shorter chain (10 or fewer carbons) fatty acids are used primarily in plastics (11). Oilseed crops are a major source of oils and fatty acids used for industrial purposes. Table 2-1 lists the fatty acids most commonly used in industrial applications. Table 2-2 presents total quantities of fats and oils used for industrial purposes in 1987 and 1988. Table 2-3 presents industrial uses of selected oils for May and April 1990.

Table 2-1—Industrial Fatty Acids

Class	Fatty acid	Most common sources
Saturated	C_{12} (lauric)	Coconut oil
	C_{16} (palmitric)	Palm oil
	C_{18} (stearic)	Tallow, hydrogenated oil
Monounsaturated	C_{18} (oleic)	Olive, tall oils
	C_{22} (erucic)	Rapeseed oil
Diunsaturated	C_{18} (linoleic)	Sunflower, soybean oil
Multiunsaturated	C_{18}	Linseed, tung, fish oil
Hydroxy	C_{18} (ricinoleic)	Castor oil

SOURCE: L.H. Princen and J.A. Rothus, "Development of New Crops for Industrial Raw Materials," *Journal of the American Oil Chemists' Society*, vol. 61, 1984, pp. 281-289.

Table 2-2—Fats and Oils: Use in Selected Industrial Products (million pounds)

	1987	1988
Soap	918	807
Paints/varnish	261	176
Resins/plastics	199	202
Lubricants	109	111
Fatty acids	2,195	2,181
Other	597	501
Total	4,279	3,978

NOTE: Fats and oils include cottonseed, soybean, corn, peanut, tall, safflower, palm, coconut, linseed, inedible tallow and grease, tung, castor, palm kernel, rapeseed, edible tallow, lard, sunflower, fish, and other miscellaneous oils.

SOURCE: James Schaub, U.S. Department of Agriculture, Economic Research Service, 1990.

Waxes are similar to oils, but are generally harder and more brittle (more saturated), and contain esters of longer-chain fatty acids and alcohols. Waxes are used in candles, crayons, and floor polishes among other uses. The United States imports many of the waxes used (table 2-4).

Resins, Gums, Rubbers, and Latexes

Resins, usually obtained from plant secretions, are solid or semisolid organic substances (usually terpenoids) that are soluble in organic solvents and insoluble in water. The most commonly used resins are produced by pine trees. Rosin, a resin mixture extracted from tall oils (a byproduct of chemical wood pulp manufacture) or from dead pine stumps has many uses in the chemical industry (table 2-5).

Many of the gums (e.g., xanthan, dextran, polytran, gullan, and pullulan) currently used are derived from seaweeds and kelps or are produced by microbial bioprocessing. These polysaccharide biopolymers are used primarily as viscosifiers (thicken-

Table 2-3—Industrial Uses of Selected Oils, April/May 1990 (thousand pounds)

Oil	Industrial use	April 1990	May 1990
Soybean	Soap	D	D
	Paints/varnish	3,038	3,442
	Resins/plastics	9,599	9,981
	Fatty acids	D	D
	Other[a]	8,020	8,725
	Total[a]	22,819	25,320
Coconut	Soap	13,849	10,255
	Paints/varnish	D	D
	Resins/plastics	175	104
	Lubricants	D	D
	Fatty acids	11,642	12,112
	Other[a]	5,200	5,903
	Total[a]	31,224	28,932
Castor	Soap	D	D
	Paints/varnish	831	410
	Resins/plastics	398	501
	Lubricants	471	418
	Other	D	D
	Total	4,385	4,438
Palm	Total	5,573	5,600
Palm kernel		D	D
Rapeseed		D	D

KEY: (D) Data withheld to avoid disclosing figures for individual companies.
[a] Total and other industrial uses includes the addition of oil to livestock feed.

SOURCE: James Schaub, U.S. Department of Agriculture, Economic Research Service, 1990.

Table 2-4—1987 U.S. Wax Imports

Beeswax	832 MT
Candelilla wax	352 MT
Carnauba wax	4,015 MT

SOURCE: U.S. Department of Agriculture, Economic Research Service, *Foreign Agricultural Trade of the United States, Calendar Year 1987 Supplement* (Washington, DC: U.S. Government Printing Office, June 1988).

Table 2-5—Industrial Uses of Rosin

Use	Percent total consumption
Rubber and chemicals	35.2
Paper sizing	33.5
Ester gums and synthetic resins	22.7
Paints, varnishes, and lacquers	2.2
Other uses	6.7

SOURCE: Joseph J. Hoffmann and Steven P. Mclaughlin, "Grindelia Camporum: Potential Cash Crop for the Arid Southwest," *Economic Botany* 40(2), April-June 1986, pp. 162-169.

Table 2-6—Use of Pulp in Paper and Paperboard Production

Use	Percent total
Newsprint	8.5
Tissue	7.5
Printing and writing	26.0
Packaging and industrial	8.5
Paperboard	49.5

SOURCE: U.S. Department of Agriculture, Forest Service, "An Analysis of the Timber Situation of the United States, 1989-2040, Part I: The Current Resource and Use Situation," 1989.

ers), flocculating agents (aggregating agents), and lubricants (11).

Natural rubber used in the United States is *Hevea* rubber imported primarily from Malaysia and Indonesia. The United States imports about 800,000 metric ton (MT) of *Hevea* rubber yearly.

Fibers

Fiber can be obtained from trees and other fibrous plants (e.g., hemp, ramie). In the United States, the primary fiber source is the forestry industry. Wood pulp is used in the making of paper and paperboard products (table 2-6).

Starches and Sugars

Starch is composed of hundreds of glucose (sugar) units bound together in branched or unbranched chains. Starch is the principal carbohydrate storage product of higher plants. Current U.S. production of ethanol requires about 400 million bushels of corn. An additional 4.5 billion pounds of cornstarch are used for other industrial purposes. Of that amount, nearly 3.5 billion pounds are used in the paper, paperboard, and related industries (primarily as adhesives). The remainder is used predominantly in the textile industry (as warp sizers) and as thickeners and stabilizers (3).

Proteins

Industrial uses of proteins include adhesives that help bind pigments to paper. However, proteins are most commonly used for food and feed purposes, rather than as industrial feedstocks.

New Industrial Crops and Uses of Traditional Crops

Chemicals with industrial uses can be derived from crops that are traditionally grown in the United States or from new crops, which must be adapted to U.S. production. New crops can be derived from the domestication of wild species of plants, or introduced from other countries. Cuphea, an oilseed that could replace coconut oil, is an example of an attempt to domesticate a wild species. Industrial rapeseed, an oilseed that produces a chemical used as a slip agent in some plastics, is cultivated in many countries and is now being adapted to U.S. production.

Research and development of new industrial crops in the United States is diverse. Table 2-7 lists some potential new crops that could be developed for U.S. production. The list is not exhaustive, but rather includes new crops that are considered to have high commercial potential based on the types of chemical compounds these plants produce. Four oilseeds (*Crambe*, rapeseed, meadowfoam, and jojoba), one new rubber, guayule, and one new fiber, kenaf, are in relatively advanced stages of development. Each of these potential new industrial crops is discussed in greater detail in *Appendix A: Selected New Industrial Crops*.

New industrial use of crops that U.S. farmers are already producing is also being pursued (table 2-8). Examples include using sunflower seed oil as diesel fuel, or using compounds derived from corn to make a road de-icer that could replace salt. These and a number of other new uses are discussed in *Appendix B: Selected Industrial Uses for Traditional Crops*.

Research is also being conducted to develop new food crops, forage crops, horticultural and ornamental crops, biomedicinal crops, and crops that produce biopesticides among others. New industrial uses of forestry crops and of ligno-cellulose derived from plant wastes are also being explored.

Changing demographic patterns in the United States have led to increased demand for many new food items. Imports of Latin and Asian fruits, grains, and vegetables have been steadily rising. Many of these crops could be grown in the United States. Some of these new food crops, like some of the new industrial crops, are drought tolerant and could be grown in areas where water shortages are becoming a problem. Additionally, some new specialty-food crops may face fewer commercialization barriers than new industrial crops (5). Horticultural crops are a rapidly growing, high-value market. Grower cash receipts for horticultural and ornamental crops grew from 5 percent of all crop receipts in 1981 to 11 percent in 1987, with estimated receipts in that year of about $7 billion (10). Examples are discussed briefly in *Appendix C: Selected New Food Crops and Other Uses*. There may also be potential to expand the use of animals and animal products as well.

Table 2-7—Potential New Industrial Crops

Crop	Compound of interest	Replacement
Oilseed:		
Buffalo gourd	Oleic acid	Petroleum/soybean oil
Chinese tallow	Tallow	Imported cocoa butter
Crambe	Erucic acid	Imported rapeseed oil
Cuphea	Lauric acid, capric acid	Coconut oil/palm kernel oil
Honesty	Erucic acid	Imported rapeseed oil
Jojoba	Wax esters	Sperm whale oil
Lesquerella	Hydroxy fatty acids	Castor oil
Meadowfoam	Long chain fatty acids	Petroleum derivatives
Rapeseed	Erucic acid	Imported rapeseed oil
Stokes aster	Epoxy fatty acids	Petroleum/soybean oil
Vernonia	Epoxy fatty acids	Petroleum/soybean oil
Gums, resins, etc.:		
Baccharis	Resins	Wood rosins, tall oils
Grindelia	Resins	Wood rosins, tall oils
Guar	Gum	Imported guar
Guayule	Rubber	Imported hevea rubber
Milkweed	Latex	Petroleum derivatives
Fibers:		
Kenaf	Pulp similar to wood	Imported newsprint

SOURCE: Office of Technology Assessment, 1991.

Table 2-8—Potential Industrial Uses for Traditional Crops

Use	Crop
Adhesives, coatings	Soybeans
Coal desulfurization	Corn
Diesel fuel	Soybeans, sunflowers
Ethanol	Corn
Degradable plastics	Corn
Ink carrier	Soybeans
Road de-icer	Corn
Super absorbants	Corn

SOURCE: Office of Technology Assessment, 1991.

This report focuses primarily on the potential benefits from, and constraints to, the development and commercialization of new industrial crops and uses of traditional crops, rather than on new food, forage, ornamental crops, etc. It also focuses on production agriculture, rather than on developing new products for the forestry industry. The rationale for focusing on industrial uses and crops is that supplying the industrial market will potentially lead to entirely new markets for agricultural products. Additionally, these industrial markets are potentially high-volume markets that could use excess agricultural capacity. Development of new edible crops is considered more likely to result in the redistribution of market share, than to expand the total market.

Proposed Benefits of Using Agricultural Commodities as Industrial Raw Materials

Proponents of the development of new industrial crops and uses for traditional crops cite many potential benefits that can accrue to society (2,9,17). Those most frequently cited include market diversification and increased farm income, improved agricultural resource utilization, reduced commodity surpluses and support payments, enhanced international competitiveness, reduced negative environmental impacts, revitalized rural economies, a domestic supply of strategic and essential materials, and decreased dependency on petroleum.

Diversification of Agricultural Markets

Currently, U.S. agriculture relies on the production of a limited number of crops, many of which are in surplus production, and are used primarily for human and livestock food. Depressed prices and price variability of these commodities results from domestic surplus production and global competition in their production and marketing, and have resulted in low and variable income for U.S. farmers. The United States has lost market share in the export of many of its major commodities.

As a result of the severe problems facing agriculture in the early 1980s, the Secretary of Agriculture convened a challenge forum in 1984 to explore new directions for agricultural products and markets. The New Farm and Forest Products Task Force was established as a result of this forum. The task force concluded that diversification of agriculture is the only alternative, and should become a national priority. The task force stated that technological innovation can potentially develop high-value products, is key to economic growth, and is necessary to avoid stagnation in mature industries such as agriculture.

Because the agricultural industry represents approximately 18 percent of the U.S. Gross National Product, the report concluded that a stronger agricultural sector will strengthen the U.S. economy. Additionally, agriculture plays a major role in the balance of payments, and development of new products could potentially lead to new export markets and possibly decrease some imports. Because of these possibilities, the task force recommended the development of new agricultural products that would use the equivalent of 150 million acres of production capacity, to be achieved within 25 years (17).

Underutilization of Land Resources

In 1989, the United States planted approximately 341 million acres of land to crops. Another 60 million acres were removed from production and enrolled in Federal programs (26 million acres in Acreage Reduction Programs and 34 million acres in Conservation Reserve Programs). Additional acreage that could potentially be used for crop production was planted to pasture (12,14,18). It has been proposed that the development of industrial markets for agricultural commodities might result in the more productive use of cropland that may currently be underutilized.

Reduction of Commodity Surpluses

Reduction of surpluses is expected to occur as new industrial markets are found for surplus crops, or as farmers shift acreage from the production of surplus crops to new crops. In 1989, the U.S. Commodity Credit Corporation had net outlays of approximately $10.5 billion to support farmers and operate Federal commodity programs (13). According to proponents, alternative and more profitable markets for the crops most heavily supported could decrease Federal commodity payments and reduce storage needs.

Enhanced International Competitiveness

In 1989, agricultural exports represented approximately 12 percent of the value of total U.S. exports (13). However, the United States has lost market share in the international trade of several commodities, and is no longer the world's lowest cost producer of many of these commodities. High commodity-support levels encourage production in other countries. Protectionist policies restrict trade. Proponents indicate that development of new uses for traditional crops or new crops could lead to the development of high-value industrial exports to replace some of the low-value bulk commodities that are currently the major U.S. exports. Many of the new crops potentially could reduce U.S. reliance on petroleum and other imports.

Improved Environmental Adaptation

Proponents argue that new industrial crops and uses potentially can offer many environmental benefits. It may be feasible to develop new crops that are better adapted to certain environments than crops that are traditionally grown (9). Of the new industrial crops discussed in this report, many are well adapted to semiarid climates. These crops have lower water requirements than many crops that are presently being grown. Irrigation may still be required to achieve commercial production levels, but probably not to the extent required for traditional crops. For regions of the Southwestern United States and the Plains States, where competing demands for water use are becoming intense, the need for crops with reduced irrigation needs is becoming more important. An added advantage of some of these drought-tolerant crops is that they are also relatively tolerant of salt. Saline buildup is a major problem in irrigated areas. Examples of potential new industrial crops that are relatively drought tolerant are bladderpod, buffalo gourd, coyote bush, guar, guayule, gumweed, and jojoba.

Potential exists to develop other new crops that are resistant to pests, weeds, and disease; these crops may require fewer chemicals than traditional crops. Additionally, development of plants that can fix nitrogen could reduce fertilizer use. Buffalo gourd and honesty are two potential new industrial crops that are perennials and provide good ground cover. Crops such as these may be used to help control soil erosion. New crops may also provide more rotation options to farmers, which could potentially decrease erosion and chemical use. Additionally, proponents feel that new uses for traditional crops may offer air quality advantages (less polluting alternative fuels), waste disposal advantages (degradable plastics), and reduce groundwater contamination (chemical delivery systems, road de-icers), among other potential benefits.

Rural Development

Proponents of development of industrial users of agricultural commodities indicate that such development could help to revitalize rural economies in two ways. First, the development of new crops and uses can provide more profitable alternatives to farmers, increasing farm income and land values. Increased farm income and land values could improve the tax base of rural communities, which could lead to improved schools, hospitals, infrastructure, etc. Services related to agriculture, such as input supplies will be needed. These services would have a multiplier effect within the economy. Second, the development of new crops and uses might stimulate the construction, expansion, or fuller use of processing and manufacturing plants. This would also create new jobs within some communities.

Strategic Materials

A domestic capacity to produce many strategic and essential materials that the United States currently imports, could reduce U.S. vulnerability to foreign events according to proponents. Strategic materials are those critical to national defense, and include many metals, natural rubber, and castor oil. Essential materials are those required by industry to manufacture products depended on daily, and include many gums, waxes, oils, and resins. The Defense Production Act (DPA) of 1950 (amended in 1980) requires that sufficient stocks of strategic materials be kept for wartime needs; stocks are managed by the Department of Defense. The mandated stockpile level of natural rubber is 850,000 short tons and that of castor oil is 5 million pounds. Since the United States is a large consumer, attempts to purchase the necessary quantities result in large price swings and current stocks are less than the levels mandated (1,8).

U.S. reliance on imports of natural rubber led Congress to pass the Native Latex Commercialization and Economic Act (Public Law 95-592) in 1978. This act was passed with the specific goal to develop a domestic natural rubber industry. In 1984, Congress amended and renamed this act the Critical Agricultural Materials Act (Public Law 98-284), which broadened the goal of the Native Latex Act to develop a domestic capacity to produce critical and essential industrial materials from agricultural commodities.

Summary

Agricultural commodities yield many chemicals that have industrial applications. Proponents feel that commercializing these applications will lead to numerous benefits for society in general, and for the rural economy and agricultural sector in particular. They feel that because of the benefits to be gained, and the lack of USDA responsiveness on this issue, legislation is needed to spur the development of these new technologies. The purpose of this report is to provide information Congress can use to assess the potential benefits of, and constraints to, developing new industrial crops and uses of traditional crops.

The potential benefits of new industrial crops and use development have not been systematically and rigorously analyzed. This report takes a first step at doing so, and presents that analysis in chapter 3. Factors involved in the research, development, and commercialization of these new technologies are discussed in chapter 4. To realize the benefits of new agricultural technology development, new processes must be adopted by manufacturers, and new crops must be adopted by farmers. Factors involved in the adoption of new technologies are discussed in chapter 5. Understanding of the factors involved in the research, development, commercialization, and adoption of new industrial crops and uses of traditional crops can aid in designing policy to achieve maximum benefits. Policy options are presented in chapter 6.

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Chapter 3

Analysis of Potential Impacts of Using Agricultural Commodities as Industrial Raw Materials

Despite claims that new industrial crop and use development will result in many benefits for society, few studies have attempted to examine whether this is, in fact, the case, and if so, what are the magnitudes of the impacts. Because of the lack of needed information, a definitive answer cannot yet be given. However, extrapolations from a few existing studies can be made, and market size and market trends for some products can be roughly estimated. Studies that examined the rural employment impacts of expanding agricultural production in the 1970s provide a framework to examine the potential employment impacts that could result from new industrial crop and use development. Analysis of technology adoption by farmers can yield insights on the potential impacts on different size farms. And, potential environmental impacts can be discussed. An examination of these issues follows.

Rural Development

Proponents of the commercialization of new industrial crops and uses for traditional crops indicate that these new technologies will revitalize rural[1] economies in two major ways: by changing farm income and number; and by creating jobs related to resource use, the processing of the raw commodities, and the production of new products. Increased farm income can have a multiplier effect, allowing farmers to spend more money in the community. Sustained income increases could also increase farmland prices and hence the tax base of many rural communities. Increased levels of production require increased inputs, transportation, and storage, and would foster the associated industries. Development of new industrial crops and uses of traditional crops could also have an impact on job creation via the construction, expansion, or fuller utilization of processing and manufacturing facilities.

Impacts of Changing Farm Income and Numbers

The crisis within the agricultural sector in the 1980s is a reflection of decreased farm income, declining asset values, and high debt load. Total farm-family income in the first half of the 1980s remained relatively stable and did not decline from 1970s levels, despite low commodity prices, because increasing off-farm income helped compensate for decreased farm income (table 3-1).[2] The value of farm assets, however, declined significantly. Lower land values decrease local government revenues. Development of new industrial markets for commodities might help to increase farm land values since these values depend in large part on future market and income growth expectations (37).

Table 3-1—Farm Family Income (dollars)

Year	Net farm income[a]	Off-farm income	Total farm family income
1960	2,729	2,140	4,869
1970	4,869	5,974	10,843
1975	8,785	9,481	18,266
1980	9,233	14,263	23,486
1981	8,378	14,709	23,087
1982	9,997	15,175	25,172
1983	10,074	15,619	25,693
1984	11,345	16,265	27,610
1985	13,881	17,945	31,826

[a] Before inventory adjustment.

SOURCE: Donn Reimund and Mindy Petrulis, U.S. Department of Agriculture, Economic Research Service, "Performance of the Agricultural Sector," *Rural Change and the Rural Economic Policy Agenda for the 1980's: Prospects for the Future,* September 1988, pp. 77-102.

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[1] Rural and nonmetropolitan are used interchangeably throughout the text. Nonmetropolitan counties are defined as those not in Metropolitan Statistical Areas (MSA), which include core counties containing a city of 50,000 or more people and a total area population of at least 100,000. Additional contiguous counties are included in the MSA if they are economically and socially integrated with the core county. Based on the 1980 Census of Housing and Population, there are 2,357 nonmetropolitan counties. (Based on the 1970 Census, there were 2,443 nonmetropolitan counties). Source: Thomas F. Hady and Peggy J. Ross, U.S. Department of Agriculture, Economic Research Service, "An Update: The Diverse Social and Economic Structure of Nonmetropolitan America," Staff Report No. AGES 9036, May 1990.

[2] Average farm-family income did not substantially change, but there were differences in subsectors of the farming population. Small, commercial-scale operations with gross sales of $40,000 to $150,000 were most negatively affected.

While farm-family income remained relatively stable, farm[3] numbers continued to decline throughout the 1970s and 1980s (table 3-2). Impacts of declining farm numbers are difficult to ascertain. In general, the land is bought by other farmers and continues to remain in production, so that total agricultural output does not significantly decline. However, declining farm numbers may negatively affect community employment levels. Multiplier effects for agriculture are generally estimated to be between 2.5 and 4, but these effects are for the total economy and do not consider location. Studies that have analyzed local rural area impacts from changes in agriculture estimate multiplier effects of less than 2. These estimates imply that in farming dependent counties,[4] for every one farm producer that leaves the industry, up to one additional job may be lost in the community (27).

Impacts resulting from changes in farm number, income, and land values will be highest in areas that are most dependent on agriculture as a source of income and employment (table 3-3). Approximately 22 percent of nonmetropolitan counties are farming dependent, and an additional 23 percent are farming important.[5] These counties are concentrated in the Plains Region (North Dakota, South Dakota, Nebraska, Kansas, western Oklahoma, and northern Texas) with some spillover in neighboring States. Between 1979 and 1985, total employment declined by 0.3 percent in these counties (6,15,51).

Development of new uses for traditional commodities would most affect the 17 percent of all nonmetropolitan counties with at least 50 percent of farm sales from corn, soybeans, wheat, cotton, or rice (i.e., agricultural-export-dependent counties). About 7 percent of all nonmetropolitan counties are both agricultural dependent and agricultural-export dependent.[6] These counties are concentrated along the Canadian border in the Northern Plains Region and in the Central Corn Belt and Delta Region (16).

Table 3-2—Farm Numbers

Year	Number
1960	3,963,000
1970	2,949,000
1980	2,433,000
1981	2,434,000
1984	2,328,000
1986	2,214,000
1989[a]	2,172,920

[a] Preliminary estimation obtained from U.S. Department of Agriculture, *Agricultural Statistic 1989*

SOURCE: Donn Reimund and Mindy Petrulis, U.S. Department of Agriculture, Economic Research Service, "Performance of the Agricultural Sector," *Rural Change and the Rural Economic Policy Agenda for the 1980's: Prospects for the Future*, September 1988, pp. 77-102.

Development of new uses could result in potentially positive or negative impacts in these regions, depending on how the new use development affects the price of the traditional crop grown in the region.

Rural Employment Potential in Agriculturally Related Industries

Studies that explicitly evaluate the rural employment potential of new industrial crops and uses of traditional crops are not available. However, many of the impacts of commercialization of new crops and uses will result from increased demand for agricultural commodities. During the 1970s, U.S. agricultural production increased rapidly in response to increased world demand for food and favorable economic conditions. The effects of increased production on rural employment in agriculturally related industries provides insight into the potential employment impacts in these industries of increased industrial demand for agricultural commodities.

Between 1974 and 1981, U.S. agricultural production expanded by 45 million acres of crops harvested (table 3-4). Employment in rural agriculturally related industries also increased during this

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[3] A farm is an establishment that sold or would normally have sold $1,000 or more of agricultural products during the year.

[4] Farming dependent counties are defined as those counties for which farming contributed a weighted annual average of 20 percent or more of total labor and proprietor income over a 5-year time period. Based on the years 1975 to 1979 and on the 1974 nonmetropolitan county definition (2,443 counties), there were 716 farming dependent counties. Using income from the years 1981, 1982, 1984, 1985, 1986, and the 1983 definition of nonmetropolitan counties (2,357 counties) there were 512 farming dependent counties. Source: Thomas F. Hady and Peggy J. Ross, U.S. Department of Agriculture, Economic Research Service, "An Update: The Diverse Social and Economic Structure of Nonmetropolitan America," Staff Report No. AGES 9036, May 1990.

[5] Farming important counties are defined as those counties for which farming contributed a weighted annual average of 10 to 19 percent of total labor and proprietor income for a 5-year time period. Using income from 1981, 1982, 1984, 1985, 1986, there were 540 farming important counties. Source: U.S. Congress, General Accounting Office, *Farming and Farm Programs: Impact on the Rural Economy and on Farmers*, GAO/RCED-90-108BR (Gaithersburg, MD: U.S. General Accounting Office, April 1990).

[6] These calculations were based on the definition of farm dependency using income data from 1975 to 1979 and on 1982 farm export levels.

Table 3-3—Share of Total Employment in Agriculturally Related Industries, 1984
(in percent)

	U.S.	All nonmetro counties	Export dependent counties	Export/farm dependent counties	Nonmetro employment (million)[a]
Total	19.5	31.3	32.4	46.0	6.22
Farm sector	4.1	13.6	15.8	29.9	2.68
Farm inputs	0.4	1.1	1.5	2.7	0.21
Processing/marketing	3.2	5.8	4.7	5.2	1.15
Wholesale/retail	9.5	8.7	8.1	6.7	1.73
Indirect	2.2	2.2	2.3	1.6	0.45

[a] Obtained from Donn Reimund and Mindy Petrulis, U.S. Department of Agriculture, Economic Research Service, "Performance of the Agricultural Sector," *Rural Change and the Rural Economic Policy Agenda for the 1980's: Prospects for the Future*, September 1988, pp. 77-102.

SOURCE: U.S. Department of Agriculture, *Agricultural Outlook*, September 1988.

Table 3-4—U.S. Agricultural Acreage[a] and Production[b], Selected Years

	1973	1981	1984
Corn:			
Acreage	62.1	74.5	71.9
Production	5.67	8.12	7.67
Wheat:			
Acreage	54.1	80.6	66.9
Production	1.71	2.79	2.59
Soybeans:			
Acreage	55.7	66.2	66.1
Production	1.55	1.99	1.86
Major crops:[c]			
Acreage	310	354	335

[a] Harvested acreage in million acres.

[b] Production is in billion bushels.

[c] Major crops include corn, sorghum, oats, barley, wheat, rice, rye, soybeans, flaxseed, peanuts, sunflowers (from 1975), cotton, hay, dry edible beans, potatoes, sweet potatoes, tobacco, sugarcane, sugarbeets, popcorn.

SOURCE: U.S. Department of Agriculture, *Agricultural Statistics*, 1988 (Washington, DC: U.S. Government Printing Office, 1988).

Table 3-5—Employment Changes in 1975-81 and 1981-84 (percent change per annum)

	1975-81[a]	1981-84[b]
Total U.S. employment	+2.9	+1.1
Total nonmetro employment	+2.9 (1,992)	+1.9 (759)
Nonmetro agriculturally related industries (total)	+1.2 (414)	–0.2 (48)
Farm sector[c]	–0.9 (158)	–1.3 (107)
Input industry	+1.6 (22)	–5.8 (45)
Processing/marketing[d]	+1.2 (84)	–1.5 (53)
Retail/wholesale[e]	+5.7 (400)	+3.3 (157)

[a,b] Numbers in parentheses are the change in total jobs for entire time period (in 1,000's).

[c] Farm sector includes agricultural services, farm proprietors, and agriculture wage and salary workers.

[d] Processing and marketing includes those related to food processing and the textile industry.

[e] Retail and wholesale includes restaurants, groceries, clothing stores, etc.

SOURCE: Donn Reimund and Mindy Petrulis, U.S. Department of Agriculture, Economic Research Service, "Performance of the Agricultural Sector," *Rural Change and the Rural Economic Policy Agenda for the 1980's: Prospects for the Future*, September 1988, pp. 77-102.

time (table 3-5), but relatively slowly. Between 1975 and 1981, rural employment in the agricultural input, and marketing and processing industries (food and textiles), increased by 106,000. Employment in the farm sector (farm proprietors, agricultural services, and farm wage and salary workers) actually declined by 158,000 jobs. The one truly bright spot was the increase in the retail/wholesale industry (groceries, restaurants, clothing stores). Employment in this sector increased by 400,000 jobs. During the early 1980s, demand for U.S. agricultural products and employment in most agriculturally related industries declined; the wholesale/retail industry continued to grow although at a slower rate (37).

These trends suggest that expanding agricultural production will increase rural employment modestly in the input supply industry. Favorable agricultural income conditions did not alter the long-term decline in farm-sector employment (over 40 percent of total rural agricultural employment), which is largely due to technological change and increased productivity. Farm numbers will likely continue to decline if agricultural productivity continues to increase. Rural employment in the retail/wholesale industry appears to be more closely tied to the condition of the overall economy than to agriculture specifically.

Rural processing-sector employment increased slowly from 1975 to 1981, in part because increased supplies were primarily exported as raw, rather than processed commodities. Employment expansion potential related to new crops and use development will depend on how much new or additional processing capacity will be needed to accommodate these new crops and uses. Processing capacity has increased in the 1980s, but the number of mills (wheat and oilseed) has declined. Oil refining capacity increased about 17 percent between 1975 and 1983. Refiners typically operate at about 75 percent of capacity (41).

Recent trends of automation and productivity increases within the processing sector will limit future employment growth potential (37). Economies of scale favor large plants; capacity can be increased with a less than proportional increase in energy and equipment costs. The number of laborers needed in larger and smaller plants is comparable because milling and processing is more capital-than labor-intensive (7,17,41). Approximately 40 percent of the wet corn, cotton, soybean oil, and flour mills in the United States have fewer than 20 employees per mill. The total employment (number of production workers plus management, maintenance workers, etc.) in soybean processing facilities is approximately 9,000 to 10,000 (2,41).

A majority of the jobs in several agriculturally related industries are in fact located in metropolitan, rather than rural, areas (table 3-6); expanding employment in these industries may benefit metropolitan regions more than rural areas. Commodity-processing plants are not always located near the site of commodity production. Transportation costs of the raw commodity relative to the processed product is a major factor in determining plant location. Access to road and rail transportation, and frequently to barge transportation, is an important consideration. For example, of the wheat grown in Kansas and milled into flour, half is milled in Kansas (primarily in mills located in urban areas) and the rest is shipped throughout the country for milling. Oilseed refining capacity is located primarily (60 percent) in urban areas, although there has been a recent trend for companies with large processing mills to build new refineries near the processing plant (17,26).

The new crops guayule and kenaf might be good candidates for new processing plant construction in rural areas and near the site of production. The rubber in guayule is contained in thin-walled cells located on the stems and branches of the shrub. Excessive handling and storage decreases rubber quality (28). Kenaf is a bulky product to transport.[7] Oilseeds, on the other hand, are generally readily transportable and storable; some modification of existing oilseed mills might suffice to accommodate many of these new crops. A case by case evaluation of processing needs and constraints is needed to assess the potential of new crops and uses to contribute to rural processing-sector employment.

Table 3-6—Distribution of Jobs in Agriculturally Related Industries

	Metro	Nonmetro
	(percent)	
Farm sector	36	64
Input supply	51	49
Processing/marketing	65	35
Food	71	29
Textiles	60	40
Retail/wholesale	82	18

SOURCE: Donn Reimund and Mindy Petrulis, U.S. Department of Agriculture, Economic Research Service, "Performance of the Agricultural Sector," *Rural Change and the Rural Economic Policy Agenda for the 1980's: Prospects for the Future*, September 1988, pp. 77-102.

Rural Employment Potential in Manufacturing

The impacts of increased industrial use of agricultural commodities on rural manufacturing employment will depend on the need to expand and modify capacity, and on the location of the expansion. In many cases, major users of chemicals derived from new and traditional crops will be firms that already exist. In some cases, substitution of agriculturally derived chemicals for petroleum-derived chemicals in production will be relatively easy, and only modification of existing plants may be needed. In other cases, either major production modifications or increased capacity will be needed; expansion will be more likely in these circumstances.

The location of new manufacturing facilities will depend on resource availability, transportation costs, availability of skilled workers, and easy access to information. Industries that are dealing with volatile or unestablished markets, rapid technical change, or other conditions that require innovative responses will generally favor metropolitan locations where they have access to information, specialized skills, and professional expertise (25). Rural areas generally have a comparative advantage over metropolitan areas in terms of availability of natural resources, and in lower tax rates, land and labor costs.

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[7] A kenaf-based newsprint mill is scheduled to begin operation in 1991, and to provide 160 jobs once full operation begins. The new mill is located in Willacy County, Texas.

The importance of resource availability and low-cost labor relative to the need for highly skilled labor will largely determine the type of personnel employed, and whether a firm locates in a metropolitan or rural area (5). Urban companies have a higher proportion of managerial and professional-technical jobs than do rural firms (table 3-7). Rural production jobs are generally lower paying, less technically skilled, and the first to be eliminated by unfavorable economic conditions (5,25).

Industries characterized by top-of-the-cycle[8] products are more concentrated in metropolitan areas, because they require technically skilled labor (table 3-8). High tech companies are an example. These firms employ relatively more scientific and technical personnel, have higher levels of research and development expenditures, manufacture more highly sophisticated products, and generally have proven to be more competitive in the world economy than companies characterized as bottom-of-the-cycle. The latter tend to use highly standardized production methods and employ relatively less-skilled labor (5).

Although rural manufacturing is characterized by a higher percentage of bottom-of-the-cycle and natural resource based industries, some top-of-the-cycle firms do locate in rural areas. In recent years, rural employment in these firms has increased, primarily in the South and West. Rural employment in top-of-the-cycle industries in the Midwest and Northeast has been declining. The greatest growth, particularly in the West, has been in rural counties adjacent to urban centers (5).

Many industries that are expected to use chemicals derived from agricultural commodities are considered to be top-of-the-cycle industries, although there are two major exceptions. The rubber and allied products industry is characterized by more routine procedures and is generally classified as a bottom-of-the-cycle (mature) industry. The paper and allied products industry is heavily reliant on natural resources. The detergent industry, a high-tech industry that uses agriculturally derived chemicals, is expanding its capacity to use vegetable oils. New plant construction, however, is in urban rather than rural areas (14).

Table 3-7—Nonmetro Share of Manufacturing Jobs by Job Type

	Metro	Nonmetro
Managerial	90	10
Professional/technical	90	10
Sales/administrative support	75	25
Precision production jobs	77	23
Machine operators	70	30
Laborers	65	35

SOURCE: David A. McGranahan, "Rural Workers in the National Economy," *Rural Change and the Rural Economic Policy Agenda for the 1980's: Prospects for the Future*, September 1988, pp. 29-47.

Table 3-8—Distribution of Manufacturing Jobs, 1984

Type of industry	Metro (million jobs)	Nonmetro (million jobs)	Proportion of nonmetro employment
Total manufacturing	15.2	4.2	21.7
Top of the cycle	7.4	1.2	13.7
Bottom of the cycle	5.6	2.0	25.9
Resource	2.2	1.1	33.3

SOURCE: Leonard E. Bloomquist, U.S. Department of Agriculture, Economic Research Service, "Performance of the Rural Manufacturing Sector," *Rural Change and the Rural Economic Policy Agenda for the 1980's: Prospects for the Future*, September 1988, pp. 49-75.

Many of the industries that are likely to use agricultural commodities as a raw material source are undergoing worldwide consolidation, and capacity is increasing. Employment trends have been mixed (table 3-9) (9).

It is difficult to determine the multiplier effects of manufacturing plants in rural locations. Total 1984 U.S. manufacturing employment was 19.4 million. It is estimated that an additional 6.5 million jobs were created supplying input services to these manufacturers; an additional 1.8 million jobs in the agricultural, mining and construction industries are also linked to manufacturing. No estimations were made of the rural-urban distribution of these jobs (54). Some studies have suggested that in rural areas, one additional community job is created for every three manufacturing jobs (47). Growth in manufacturing employment in nonmetropolitan areas aver-

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[8] Product development goes through many phases, from conception to routine manufacturing. Products at the top of the cycle are in the earlier phases of development. These phases include conception and prototype development, and the establishment of the manufacturing procedures. Products at the top of the cycle use a high proportion of highly skilled technical labor. Top of the cycle industries are those characterized by having top of the cycle products. These firms are generally the innovative (high-tech) firms. Bottom of the cycle products are those that are more highly developed and for which the manufacturing process is highly standardized and routine. Bottom of the cycle industries use a higher proportion of labor with lesser technical skills.

Table 3-9—Manufacturing Employment Trends of Industries Potentially Using Industrial Agricultural Commodities

	1989 employment level	Trend (1979-89) percent per annum change
Plastics and synthetic materials	187,000	-1
Paints and allied products	63,000	-1
Soaps, cleaners, toilet goods	161,000	+1
Rubber and miscellaneous products	840,000	+1
Petroleum and coal products	163,000	-3

SOURCE: *Chemical and Engineering News*, "Employment in the U.S. Chemical Industry," June 18, 1990, p. 60.

aged 1.4 percent per annum between 1982 and 1986, and jumped to 2.6 percent in 1987.

Potential Rural Employment Implications

Agriculturally related industries are a significant, but declining, source of employment in rural communities. Employment trends in the 1970s and 1980s suggests that large increases in demand and production of agricultural commodities will be needed to increase employment significantly in rural agriculturally related industries. Agriculturally dependent communities are likely to benefit the most. Significantly, much of the employment growth in agriculturally related industries is likely to occur in metropolitan, rather than rural, communities. Rural areas are likely to have a comparative advantage with firms for which natural resources or low-cost labor are important considerations. As noted, firms requiring highly skilled labor, are likely to concentrate in metropolitan regions. These include several of the industries that are expected to commercialize products derived from agricultural commodities. These studies and industry trends suggest that commercialization of industrial uses for agricultural commodities may have modest impacts on rural employment, and that much of the employment growth may be in metropolitan communities. From society's point of view, new job creation may be desirable regardless of location, but firm location in metropolitan areas does not revitalize rural economies.

Proponents of industrial crops and use commercialization argue that even modest rural employment increases are worth pursuing. This is true only if equivalent benefits cannot be obtained by other methods at lower cost. The cost-effectiveness of this strategy has not been evaluated and conclusions cannot be made. Historically, however, social returns to agricultural research investments have been high, ranging from an estimated 45 to 135 percent (30).

Regional Specialization

Many new crops under development potentially can be grown in several regions of the United States (table 3-10). However, like traditional crops, some regions may have a production advantage over others, and regional specialization of production may result. Thus, the introduction of new crops or uses of traditional crops may benefit some regions, while having little effect on others.

Two examples illustrate the point. Kenaf can be grown throughout the South, but appears to be particularly attractive compared to the net returns of other options in parts of Texas. This area is likely to be one of the earliest producers of kenaf. *Crambe* and rapeseed can be grown extensively in the United States, but *Crambe* is more tolerant of dry conditions than rapeseed. *Crambe* may have an advantage over rapeseed in the Plains region, whereas rapeseed, particularly the winter varieties, may have advantages in the Southeast (20).

Transportation costs could also play a role in determining production location. Prices received by farmers reflect transportation costs. Farmers at great distances from processing plants receive lower prices. For example, soybean producers in the Plains region receive lower prices than producers in the Midwest, in part due to lower quality (less oil), but largely due to transportation costs (41). Lower prices decrease the attractiveness of a crop to farmers. A new crop's competitiveness may be enhanced if it is grown in an area where it is relatively easy to convert existing processing facilities to accommodate it.

Agricultural Sector Stability

Market failure and macroeconomic policy are the primary factors affecting the stability (extent of farm price and net return variability over time) of agriculture (48). Market failure arises from uncertainty (e.g., such as weather and assymetric information between buyers and sellers). Development of new marketing institutions, or use of existing institutions that reduce marketing uncertainties (e.g., forward contracting, futures and insurance markets) potentially could reduce inefficiencies in the marketing of industrial crops and uses of traditional

Table 3-10—Likely Production Locations of New Crops

Crop	Location
Oilseeds:	
Buffalo gourd	Southwest
Chinese tallow	Southeast
Crambe	Midwest/Southeast/Plains States
Cuphea	Northwest/Midwest
Honesty	Northern States/Alaska
Jojoba	Southwest
Lesquerella	Southwest
Meadowfoam	Pacific Northwest
Rapeseed	Northwest/Plains States/ Midwest/Southeast
Stokes aster	Midwest/Southeast
Vernonia	Southeast
Gums and resins:	
Baccharis	Southwest
Grindelia	Southwest
Guar	Southwest
Guayule	Southwest
Milkweed	Plains/Southwest/West
Fibers:	
Kenaf	South

SOURCE: Office of Technology Assessment, 1991.

crops. Diversifying agricultural production potentially could reduce adverse weather impacts.

Macroeconomic policy influences the price of commodities and land values in the United States, as well as exchange rates, interest rates, inflation, and rates of economic growth here and abroad. During the 1970s, attempts to recycle petrodollars sparked rapid economic growth in developing countries. Coupled with the switch from fixed to flexible exchange rates, this growth led to an export boom for U.S. agricultural commodities. At the same time however, inflation in the United States was rising and the Federal deficit was being paid for by monetary policy. In late 1979, the Federal Reserve began to disinflate the U.S. economy. This severe monetary action led to high interest rates and values of the U.S. dollar as Federal Government deficits were now being financed by foreign savings. High debt loads at high interest rates, coupled with high U.S. dollar values, meant that developing nations could no longer afford to pay for U.S. agricultural commodities and exports plummeted. Because nearly 1 in every 3 acres planted in the United States is destined for the export market, decreasing exports lead to declining U.S. farm income and land prices (42).

The roller-coaster ride that U.S. agriculture has undergone since 1975 points out the vulnerability of that segment of the economy to macroeconomic policy (3,42). Several industries that would use chemicals derived from agriculture are also susceptible to macroeconomic policies, and display highly variable demand for raw commodities. The rubber industry serves as an example. Nearly 60 percent of all rubber used in the United States is used to make tires. Tire production is intimately linked to the automobile industry, which is highly vulnerable to interest rates. Between 1977 and 1989, U.S. rubber consumption has fluctuated between 5.3 and 7.4 billion pounds (45).

Thus the impact of new crops and uses of traditional crops on agricultural stability may be small. While new crops can offer production opportunities that help limit the risk from adverse weather, disease, or insect problems, development of new uses for traditional crops potentially could have the opposite effect by increasing monoculture. Development of new risk-reducing marketing arrangements, or increased use of those that exist could lead to some increased stability, as could diversification of markets for agricultural commodities. As noted, however, many industries that are expected to use agricultural commodities fluctuate in their use of raw materials. Whether these markets will lead to increased stability has not been adequately analyzed. Macroeconomic policy will continue to be a key factor in agricultural stability.

International Implications

Some new crops being developed potentially could replace a significant proportion of major exports of some developing countries, which could result in economic stress for these countries. *Cuphea*, for example, could substitute for coconut and palm kernel oil. Tropical oils represent 11.5, 2.5, and 7.5 percent of the total 1985 exports of Malaysia, Indonesia, and the Philippines respectively (59). Additionally, *Hevea* rubber, which potentially could be at least partially replaced by guayule, is a major export of Malaysia and Indonesia. Some of these countries, the Philippines in particular, are considered to be strategically important to the United States.

In addition to the strategic implications, there are potential long-term impacts on U.S. export markets to consider. Studies indicate that the future growth of U.S. exports depends largely on expanding markets in developing countries rather than industrialized nations (39). Replacing the exports of these countries narrows their opportunities for economic development and for attainment of scarce foreign reserves to purchase U.S. products.

An additional consideration is trade relationships with industrialized nations. For example, the export of corn gluten meal (a byproduct of ethanol production) to Europe is a contentious issue between the United States and the European Community. The economic competitiveness of ethanol production depends in part on having markets for corn gluten meal; being able to export the meal decreases the downward price pressure that ethanol production has on soybeans. Understanding of potential international impacts is needed to help anticipate possible trade disputes.

Competition With Current Crops and Interregional Impacts

A major goal in the development of new industrial crops and uses is to provide new markets that do not compete with markets currently supplied by traditional crops. Many primary uses being developed will not, but there will be some exceptions. There may, however, be considerable competition with traditional crops through competition in the byproduct markets. It cannot be unambiguously stated that new industrial crops and uses of traditional crops will not compete for markets currently supplied by traditional crops.

If new crops compete directly for markets with crops that are currently being grown, the latter could fall in price, resulting in decreased income to producers of that crop. For example, some new oilseed crops could potentially compete with soybeans. Examples are *Vernonia* and *Stokesia* which produce oils containing epoxy fatty acids, that potentially could replace the approximately 100 to 180 million pounds of soybean, linseed, and sunflower seed oil that are converted to epoxy fatty acids for industrial use each year (the equivalent of 8 to 15 million bushels of soybeans) (36). Additionally, potential byproducts of glycerol and high-protein meals could compete with soybean oil for industrial markets and for use as livestock feeds (2).

New uses for traditional crops may also affect demand for current crops. For example, many new uses being developed for corn only use the starch component of corn. Oil, distillers dried grains, and corn gluten meal are produced as byproducts. The oil competes with oils derived from oilseeds, particularly soybeans. The distilled dried grains and gluten meal compete directly with soybean meal as high-protein livestock feeds. Increased supplies of these corn byproducts will decrease the price of soybeans, possibly by up to 4 cents a bushel per 100 million additional bushels of corn used (60,61).

Competition with traditional crops would have different regional impacts. For example, soybean production is located primarily in the Corn Belt, Southeast, and Delta regions of the United States. Soybean producers in the Corn Belt can switch to corn production; producers in the Southeast and Delta regions will have problems. Production costs of soybeans are also higher in the Southeast and Delta regions. The result could be a decrease in farm income in those regions (41). Finding new uses for soybean oil or meal may help to alleviate some of the potential impacts on soybean prices.

Small Farm Impacts

Most new crops can be grown on large and small farms (defined in this report as those with less than $100,000 in sales), but some advantages may exist to their production on large farms. Since many of the crops are bulk commodities, they may have relatively low unit values. Minimizing production costs will be important. Economies of scale, particularly for machinery, might help lower production costs for large farms. Additionally, farms that have a larger financial base may be able to absorb the economic risk associated with new crops better than smaller farms. Some new crops, such as jojoba and guayule are perennials that require several years to reach maturation. Crops such as this require large upfront costs and have long payback times on the investment. This could create serious cash-flow problems, particularly for small farm operators or those with little access to financing.

A correlation exists between farm size and speed of adoption, with larger farms adopting technology first (55). Small farm operators may be unwilling or unable to adopt new technologies. For example, a study of Oklahoma farmers showed that although production of specialty vegetables could raise farm income for part- and full-time farmers who operated small enterprises (defined in the Oklahoma study as those having sales of less than $40,000), fewer than 6 percent of the farmers in these categories expressed a willingness to grow specialty vegetables (40). Thus, even if a new crop can be grown on small-sized farms, operators of large farms may be the earliest adopters and, thus, may capture most benefits.

The income impacts of new uses for traditional crops will be affected by farm commodity programs. For crops covered, commodity programs buffer the effects of changing market prices on farm income. High market prices are offset by lower deficiency payments, and low program participation. When market prices are low, program participation by farmers is high, and modest changes in market prices have little impact on total farm income. Impacts of higher market prices would be greatest for farmers who do not participate in commodity programs or for producers of commodities not covered by commodity programs. Participation rates are lowest among the smallest and largest farms. Producers who specialize in the production of cash grains[9] have the highest rates of participation (table 3-11). In 1987, 83 percent of all cash grain farmers participated in farm programs, more than 83 percent of the feedgrain, cotton, wheat, and soybean acreage was grown on farms operated by program participants (table 3-12) (32).

Significant changes in aggregate income would occur only if market prices exceed target prices, or if demand is high enough to reduce set-aside acreage requirements significantly. It is estimated that ethanol production from corn would need to increase current production levels by a factor of 3 to 4 to approach that situation[10] (60).

Many small farm operators do not rely on farm income for the majority of family income (table 3-13) (57). These statistics suggest that modest changes in market prices for many of the traditional crops that are in surplus may not result in large increases in income for small-sized farms, and small-farm operators may be unable to adopt new crops. Policies that help small-farm operators accept the added risks of new crops, and programs that teach new management skills would increase the likelihood of new crops and uses benefiting small-farm operators.

Table 3-11—Participation in Federal Farm Programs by Farm Size, 1987[a]

	Percent participating[b]
Harvested acres	
1 to 99	20.6
100 to 199	59.9
200 to 499	78.0
500 to 999	87.0
1,000 to 1,999	87.3
Greater than 2,000	81.6
Farm sales class	
Less than $1,000	6.7
$1,000 to $4,999	12.0
$5,000 to $9,999	23.3
$10,000 to $24,999	38.8
$25,000 to $49,999	54.3
$50,000 to $99,999	62.2
$100,000 to $249,999	65.7
$250,000 to $499,999	60.0
$500,000 to $999,999	49.7
Greater than $1,000,000	34.8

[a] Note that 1987 was a year characterized by low commodity prices, and participation rates in agricultural programs were high.

[b] Participants are defined as farm operations that receive any cash payments or payments in kind from Federal farm programs. These include benefits such as deficiency payments, whole herd dairy buyout, support price payments, indemnity programs, disaster payments, paid land diversion, inventory reduction payments, or payments for approved soil and water conservation projects. Participants also include farmers who place any portion of their production in the Commodity Credit Corporation for nonrecourse loans or have any acreage under the annual commodity acreage adjustment programs or the conservations reserve program.

SOURCE: Merritt Padgitt, U.S. Department of Agriculture, Economic Research Service, "Production, Resource Use, and Operating Characteristics of Pariticpants and Nonparticipants in Farm Programs," *Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report*, September 1990, pp. 48-54.

The question also arises of who captures the value added[11] of new products. For example, in 1987 consumers spent $377 billion for foods produced on U.S. farms. About 25 percent ($94 billion) went to farmers and the remainder went to the food industry for processing, handling, and retailing. For many food crops, such as grains and oilseeds, the farm value is a small share of the retail price (13). Studies that assess who captures the benefits of the value added from industrial uses of agricultural commodities are needed.

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[9] For farms to be classified as a particular specialty, it must derive 50 percent or more of its sales from a special class of products. Cash grain farms include those specializing in the production of wheat, feed grains (corn for grain and silage, sorghum, barley, and oats), soybeans, sunflowers, dry beans, peas, or other grain crops.

[10] This estimation was made using target prices established in the 1985 Food Security Act. The 1990 Farm Bill froze target prices at 1990 levels, so the general principal still holds.

[11] Value added is the sum of wages, interest, rent, profit, depreciation, and indirect business taxes in the sector or industry considered.

Table 3-12—Participation in Federal Farm Programs by Crop Acres, 1987[a]

Crop	Percent participating[b]
Feed grains[c]	83.0
Soybeans	85.8
Wheat	88.6
Cotton	89.5
Rice	91.1
Peanuts	75.7
Tobacco	47.9

[a] Note that 1987 was a year characterized by low commodity prices and participation rates in farm programs were high.

[b] Participants are defined as farm operations that receive any cash payments or payments in kind from Federal farm programs. These include benefits such as deficiency payments, whole herd dairy buyout, support price payments, indemnity programs, disaster payments, paid land diversion, inventory reduction payments, or payments for approved soil and water conservation projects. Participants also include farmers who place any portion of their production in the Commodity Credit Corporation for nonrecourse loans or have any acreage under the annual commodity acreage adjustment programs or the conservations reserve program.

[c] Includes acres of corn for grain and silage, and sorghum, barley, and oats for grain.

SOURCE: Merritt Padgitt, U.S. Department of Agriculture, Economic Research Service, "Production, Resource Use, and Operating Characteristics of Paritcpants and Nonparticipants in Farm Programs," *Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report*, Septermber 1990, pp. 48-54.

Environmental Impacts

New industrial crops and uses of traditional crops potentially could have positive or negative environmental impacts. Replacing salt with calcium magnesium acetate (a new product) as a road de-icer could reduce the soil and water contamination problems associated with salt. Use of starch, or starch-vegetable oil mixtures as a delivery system for herbicides and pesticides potentially could mitigate rapid leaching of these chemicals. Degradable plastics may in the future help alleviate waste disposal problems, but at the present time, too many questions exist regarding the extent of degradation, the chemicals released, and the impact on plastic recycling to state that degradable plastics will have a positive effect on the environment. Likewise, using ethanol as a gasoline additive decreases carbon monoxide emissions, but may increase volatile hydrocarbon emissions. Increased uses for corn could increase corn production, which is chemically intensive. The implications this might have on groundwater pollution need further investigation.

Many new crops may be better suited to certain environments than crops that are currently being grown there. Many new crops are drought tolerant and their water demands are much lower than many traditional crops. In areas where irrigation is becoming more expensive, these new crops could be attractive. Additionally, several crops provide good ground cover and possibly could reduce soil erosion.

Table 3-13—Income Sources by Sales Category, 1988

Sales category	Percent total income from off-farm sources[a]	Percent gross cash farm income from government	Percent of total farms
Less than $10,000	89	4	45
$10,000 to $19,999	74	7	12
$20,000 to $39,999	49	10	11
$40,000 to $99,999	24	11	14
$100,000 to $249,999	13	11	12
$250,000 to $499,999	6	9	4
Greater than $500,000	3	4	2

[a] Total income is the sum of total off-farm income and total gross cash farm income.

SOURCE: Office of Technology Assessment, 1991. Calculated from data contained in U.S. Department of Agriculture, Economic Research Service, "Financial Characteristics of U.S. Farms, January 1, 1989," Agriculture Information Bulletin No. 579, December 1989.

For many potential new crops, information concerning pest, weed, and disease problems is lacking. In the wild, plants may be relatively free from pests and disease, but intensive cultivation creates a different environment, one that is often favorable for the development of pest and disease problems. This is true with traditional crops and appears to be what is happening with jojoba, a new crop now being cultivated in the Southwest. In the wild, jojoba is relatively free of pests and diseases, but cultivated stands are beginning to experience problems (29).

The availability of new crops will provide more options to farmers who wish to rotate crops. Crop rotation patterns can be used to reduce soil erosion and chemical and fertilizer applications. However, in most cases, crop rotation is limited in U.S. agriculture primarily because of economic disincentives, some of which stem from agricultural commodity programs, rather than, lack of crop options. Development of new crops is unlikely to increase crop rotation significantly without changes in economic incentives. Changes in the 1990 Farm Bill may improve this situation.

Several potential new industrial crops are not native to the United States. Commercialization in the United States will require the introduction of alien species. Historically, new crops have been introduced without problems; most of the major crops produced in the United States today are not native. However, on occasion, the process does go awry with severe repercussions (34). Johnson grass is an example. Originally and purposely introduced into U.S. agriculture as a superior forage crop, it is today a serious weed requiring widespread use of herbicides. It is also a close relative of sorghum and is able to cross-fertilize with that crop rendering a useless offspring. Sometimes a newly introduced species, while relatively benign itself, may serve as a host for diseases of other plants. A historical example is common barberry, which served as a host for wheat stem rust, a fungus that debilitates wheat. A national eradication program was needed to destroy this plant (24). Domestication of native wild species raises issues of weediness potential and cross-hybridization with wild relatives. These issues have not been adequately evaluated.

Some new crops and uses will involve biotechnology; crops may be genetically engineered to have new characteristics. Many environmental concerns have been raised concerning the release of these plants. Genetically engineered organisms will need regulatory approval. Well-defined regulations and regulatory agencies operating in a timely and effective manner will be needed to ensure speedy commercialization of biotechnologically derived new crops and uses of traditional crops.

The potential environmental impacts of large increases in land use for agricultural production have not been adequately evaluated. Major changes in land use patterns will have implications for erosion, ground and surface water contamination, wildlife, and non-agricultural plants among others.

Commodity Surpluses and Government Expenditures

Development of new uses for traditional crops that are in surplus could potentially reduce those surpluses. Current carryover stocks of some major commodities are low due to particularly adverse weather conditions in recent years, but historically, large surpluses of some commodities have existed (table 3-14). Currently, agricultural commodity programs strongly encourage the planting of some crops that are in surplus. Farmers will need strong economic incentives to decrease production of these commodities and begin producing new crops.

Table 3-14—Commodity Stocks
(million bushels)

	Wheat	Corn	Soybeans
1985/86[a]	1,905	4,040	536
1986/87	1,821	4,882	436
1987/88	1,261	4,259	302
1988/89	702	1,930	182
1989/90[b]	536	1,344	239
1990/91[b]	945	1,236	255

[a] Marketing year beginning June 1 for wheat, and September 1 for corn and soybeans.

[b] Based on Nov. 8, 1990 estimates.

SOURCE: U.S. Department of Agriculture, Economic Research Service, *Agricultural Outlook*, July 1990.

The development of new crops can reduce surpluses if farmers shift acreage from the production of surplus crops to the new crops. However, this might not occur, because farmers may produce new crops on acreage shifted from the production of minor, non-surplus crops. New crops may be more economically competitive with the latter than they are with the surplus commodities. If this is the case, then the development of new crops may not result in a significant reduction of surpluses. Not enough information is available to determine the impact of new industrial crops on surpluses.

Similarly, it is not possible to state unambiguously that new industrial crops or uses of traditional crops will reduce Federal expenditures. Currently, for example, ethanol derived from cornstarch is competitive as a fuel additive only because it is heavily subsidized via excise tax exemptions. An Economic Research Service (ERS) study indicates that an expansion of the ethanol industry will reduce agricultural commodity support payments, but this reduction will be offset by increased subsidies resulting from lost excise tax revenues (60).[12] The Federal Government still pays, but the program that provides the funding has changed. New uses that utilize commodity program crops, and are competitive (without subsidies) with available alternatives could possibly lower Federal expenditures.

An additional consideration is the potential impact that new uses of one crop may have on other crops covered by commodity programs. For example, increased ethanol production from cornstarch is expected to decrease the price of soybeans. Soybeans are covered by nonrecourse loans. Traditionally, the market price of soybeans has been higher than the loan rate, and support payments have not been needed (41). It is not clear whether the price of soybeans would drop low enough for high farmer participation and defaults on nonrecourse soybean loans, but this is a possibility. Under these conditions, Federal agricultural commodity expenditures for soybeans would increase. Alternatively, rising corn prices may cause some livestock producers to switch to other grains for feed. Increased use of wheat, for example, could raise wheat prices. Wheat is also supported by commodity programs and these expenditures might decrease. The interactions in commodity markets are complex and changing one aspect on the market will result in many secondary impacts. The net effect of these impacts and how they would affect Federal commodity expenditures are not known.

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[12] A recent GAO study (U.S. Congress, General Accounting Office, *Alcohol Fuels: Impacts From Increased Use of Ethanol Blended Fuels,* GAO/RCED-90-156 (Gaithersburg, MD: U.S. General Accounting Office, July 1990) examining this issue indicated that there would be a net positive impact on government payments for the time period examined in their study. The GAO and USDA studies used different econometric models of the agricultural sector and slightly different assumptions. The USDA study used a longer time horizon and different expansion levels than the GAO study. The negative cumulative net effects on government payments occurred late in the time frame used by the USDA study.

Potential To Supply Strategic Materials and Replace Petroleum

It is possible to develop a domestic capability to produce many strategic and essential industrial materials.[13] This capability could lead to an increased sense of security and reduce vulnerability to external political factors. Many potential new crops that could supply strategic and essential materials are in the early stages of development and numerous technical constraints must be overcome. Many new and strategically important crops are not economically competitive with available alternatives. Development takes many years, however, and today's research lays the groundwork necessary for future competitiveness and helps provide flexibility to respond to changing needs and economic environments.

Guayule (rubber) is an example of a new strategic crop that is technically more developed, but is not yet price-competitive with imported natural *Hevea* rubber. However, because of its strategic importance, the Department of Defense has stated in a Memorandum of Understanding with the Department of Agriculture that it will seek to ensure that a significant portion (20 percent) of its annual tire purchases are tires made from guayule rubber, provided: that the initial price of guayule rubber is not over three times that of *Hevea* rubber; and that within 5 years of initial purchase, the price of guayule rubber becomes competitive with that of *Hevea* rubber (31). This arrangement provides a market pull for the development of guayule in the United States despite the fact that it is not currently economically competitive with *Hevea* rubber.

The potential to replace petroleum is an important issue and an extensive and detailed analysis is beyond the capacity of this study. A few pertinent observations can be noted however. Petroleum is used to produce many products in the United States, including gasoline, diesel fuel, residual oil (used in boilers), jet fuel, chemical feedstocks, and miscellaneous products (including kerosene, lubricants, etc.). Transportation fuels are by far the largest use, and account for nearly 64 percent of the petroleum used (53). Chemical feedstocks represent another 7 to 8 percent of petroleum use (10). Many of the new industrial crops and uses of traditional crops potentially could replace some of these uses.

Development strategies required to significantly replace petroleum uses in fuel and the chemical feedstocks industries are likely to be different. This is because fuels are sold in energy units, while chemical feedstocks are sold in weight units. Conversion of carbohydrates (sugars and starches) to ethanol, for example, conserves energy, but mass is lost (CO_2 is lost). This puts an additional burden on using biomass in the chemical feedstock industry (22). Chemical purity is required for the chemical industry; fuel uses generally tolerate greater contamination. Chemicals obtained from biomass sources generally have a higher level of contamination than those derived from petroleum cracking (10).

The potential to replace the largest quantity of petroleum is to develop substitutes for transportation fuel. Use of biomass as a fuel source, in general, is impeded by the size of the United States fuel industry, low energy content, seasonality, the dispersed geographic location of supply, and lack of supply infrastructure (22,53). Potential fuel replacements derived from agricultural commodities include ethanol to replace gasoline and vegetable oils to replace diesel fuel.

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[13] Strategic materials are defined as those materials that would be needed to supply the military, industrial, and essential civilian needs of the United States during a national emergency, and are not found or produced in the United States in sufficient quantities to meet such needs. Castor oil and natural rubber are strategic materials. Essential materials are those required by industry to manufacture products depended on daily.

At this time, corn is the least expensive biomass feedstock to use for ethanol production. Current ethanol production replaces less than 1 percent of total U.S. gasoline consumption (62).[14] Significant replacement of gasoline using ethanol derived from corn would require an increase in ethanol production of several orders of magnitude. This would result in many energy, environmental, and economic effects, some of which will be positive and some negative (see box 3-A).

A recent OTA study found that these concerns, coupled with the high direct costs of ethanol production from corn, imply that the prospects of substantial increases in ethanol use in transportation are not favorable (53). A mitigating factor might be the recent passage of the Clean Air Bill, which mandates use of oxygenates (compounds high in oxygen content such as ethanol among others) in fuel for some cities that do not meet Clean Air Standards. Additionally, improvements in the conversion of lignocellulose to ethanol, instead of starch to ethanol, might improve the economics of ethanol use for transportation fuels. These technical advances are not expected to occur prior to the year 2000, and the implications of this development for the farm sector are not clear at this time.

The potential for vegetable oil-based diesel fuel is similarly difficult to predict. The United States consumes approximately 40 billion gallons of diesel fuel each year, with approximately 10 percent of this total used in agriculture (23). Using soybean oil, just for agricultural uses, would require an additional 15 to 20 million acres of production over current levels. This would increase the price of soybean oil for food uses. The increased meal produced would likely saturate the soybean meal markets. If the oil is converted to monoesters for use, then the glycerol byproduct will also need to be marketed. Using crops that produce more oil per acre, such as sunflowers and possibly rapeseed, could potentially improve the situation, as could finding uses for the meal other than for livestock feed.

Alternatively, new and traditional crops can be used to produce commodity chemicals, rather than fuel. Currently, about 7 to 8 percent of the petroleum used in the United States is used to produce commodity chemicals (10). Five compounds derived from petroleum account for 70 to 75 percent of all primary feedstocks (table 3-15). These compounds and their derivatives represent 50 to 55 percent of all organic feedstocks produced by the chemical industry (8).

Table 3-15—Major Primary Feedstocks Derived From Petroleum

Feedstock	U.S production, 1989 (billion lbs)
Benzene	11.7
Ethylene	35.0
Propylene	20.0
Toluene	5.8
Xylene	5.8

SOURCE: *Chemical and Engineering News*, Apr. 9, 1990.

The extent to which petroleum is replaced by chemicals derived from agricultural commodities will depend on economic competitiveness, superior performance, availability of other substitutes, and on the net energy balance of crop production (i.e., the ratio of energy output relative to the energy used for agricultural production and processing). Today, economics do not favor using agricultural commodities to derive most commodity chemicals, but rising petroleum prices and improvements in processing technologies could alter that situation (12,22,33).

Replacement of petroleum-derived chemicals with plant-derived chemicals can be done in two ways: direct or indirect substitution. Direct substitution involves the replacement of a petroleum-derived chemical with an identical biomass-derived chemical. This strategy has the advantage of having acceptable products and markets that already exist. The disadvantage is that it is difficult for plant-derived chemicals to compete economically because the petroleum chemical industry is highly integrated, is flexible in the chemical mix produced, and has large economies of scale. Additionally, the chemical industry may be able to adjust prices substantially in response to threatened competition.

The indirect replacement strategy requires developing plant-derived chemicals that have a slightly different chemical composition, but the same functions as petroleum-derived chemicals. In this case, benefits in terms of superior performance, improved storage or supply characteristics, or improved envi-

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[14] One bushel of corn produces approximately 2.5 gallons of ethanol. U.S. production of ethanol uses approximately 350 to 400 million bushels of corn (approximately 5 percent of corn production).

Box 3-A—Social and Market Impacts of Ethanol

For crops that are in surplus, it is hoped that the development of new uses will increase demand and raise prices for the commodity, increase farm income, decrease surpluses, decrease Federal commodity payments, increase job creation in rural communities, and in some cases, have positive environmental impacts. An example will help to illustrate some of the complications that might occur. The analysis is taken from a USDA/ERS study on the potential impacts of increasing ethanol production from corn (51,52). The analysis assumed that commodity price supports would remain similar to those in the 1985 Food Security Act, the Federal excise tax exemption would be extended, and continuing export markets for corn gluten meal would exist. Estimation of impacts is based on an expansion of ethanol production to about 2.7 billion gallons of ethanol per year by 1995, which would require an additional 800 million bushels of corn annually. Such a scenario is unlikely to occur without changes in economic incentives of ethanol production or possibly government legislation mandating increased use of ethanol. Additionally, the price and policy scenarios used in the model may change, resulting in different outcomes than those predicted. However, the analysis is illustrative of the types of impacts that can occur when new uses for traditional crops are developed, and is valuable in showing how complex the interactions in the agricultural commodity markets are.

Commodity Prices—Increasing the production of ethanol using corn as a feedstock will result in higher corn prices. It is estimated that corn prices will increase approximately 2 to 4 cents per bushel, for each additional 100 million bushels used to produce ethanol. However, corn is not the only commodity that will be effected. Corn is used primarily as a livestock feed. As the price of corn rises, livestock producers may switch to other feed grains such as wheat or sorghum. The increase in demand could result in some increase in prices for these grains. Ethanol production from corn requires only the starch. Produced as byproducts are corn oil and distillers dried grains (from dry mill processing) or corn gluten meal and feed (from wet mill processing). Corn oil competes in the edible oil market with the oil obtained from oilseed crops such as soybeans and sunflowers. Additionally, distillers dried grains and corn gluten meal and feed compete with soybean meal as a high-protein livestock feed. Thus the value of soybeans decreases. In the short run, prices could decrease as much as 20 percent. In the long run, it is expected that farmers will shift out of soybean production to the production of other crops, particularly corn, and the decreased supply of soybeans will help raise the price again.

Livestock Sector—Changing prices for grains and protein meals could affect livestock production. Ethanol production below 3 billion gallons is not expected to significantly affect livestock production because higher grain prices will likely be offset by lower protein meal prices. The impacts on livestock production will depend on how easily ethanol byproducts can be substituted for corn in the feed rations. Limited opportunities for substitution could result in higher feed prices and lower livestock production. Substitution opportunities are likely to be different for beef, pork, and poultry. Lower livestock production could result in higher meat prices for consumers. Estimates are that at 2.7 billion gallon production, food costs may increase an additional $150 million annually (51,52).

Farm Income—Higher corn and grain prices will affect the income of farmers producing those commodities. Farmers who produce corn and who do not participate in commodity programs will benefit the most from higher corn prices. The benefits to corn producers enrolled in the corn commodity program will not be as high because the commodity program to some extent buffers the effect of higher market prices (i.e., higher market prices result in lower deficiency payments to farmers). In general though, corn producers will experience a higher income from

ronmental conditions, must outweigh any potential cost disadvantages (10,22). Indirect substitution using primarily oils and resins does occur, but the high variability of supply and price has restricted these uses.

Technically, starch derived from corn (or other sources) could be used to make several commodity chemicals, many of which are intermediates in the production of other chemicals. The markets for some of these chemicals (e.g., ethylene) are large. Some smaller markets (e.g., ketones and alcohols) might be more likely candidates for development. Other potential substitution opportunities lie with chemicals with high oxygen contents, since plant-derived chemicals usually contain oxygen, while petroleum-derived chemicals do not. Examples include sorbitol (food processing), lactic acid (thermoplastics), and citric acid (detergents) (12). Starch can also be used to produce polymers used either alone or in combination with other compounds such as plastics. Currently, biomass-derived plastics are not economically competitive except in a few specialty high-value markets (e.g., surgical sutures). Major technical advances are still needed (10).

increased corn prices. Additionally, producers of other grains, for example wheat, may also experience higher incomes if the prices of these grains also increases. Soybean farmers will lose income because of the competition in the oil and high-protein meal markets. The differential price changes for grains and soybeans could result in interregional income shifts. Farmers in the Corn Belt can switch soybean acreage to corn. Producers in the Southern United States, particularly the Delta region cannot. It is estimated that farm income in that region could decrease by 5 to 7 percent. Total gross receipts from crop production are expected to increase $1 to $2 billion if ethanol production is increased to 2.7 billion gallons (51,52).

Farm Program Costs—Increases in ethanol production will decrease farm program costs because of the increases in grain prices, but will be offset by tax losses resulting from the Federal excise tax exemption for ethanol. Higher grain prices result in fewer participants in the farm commodity programs, decreased deficiency payments, and decreased storage costs. These changes would occur not only in the corn program, but also in the programs for other grains such as wheat, sorghum, oats, and barley. It is estimated that if commodity supports remain at the same levels established in the 1985 Food Security Act, then ethanol production levels of 2.7 billion gallons by 1995 could result in commodity program savings of about $9 billion between 1987 and 1995. However, there is a possibility for increases in Commodity Credit Corporation stocks of soybeans if the price of soybeans decreases sufficiently. Soybeans are covered by non-recourse loans, but generally soybean farmers have not enrolled in the program because market prices have been higher than the loan rate. Between 1987 and 1995, it is estimated that Federal tax losses due to the excise tax exemption on a 2.7 billion gallon ethanol industry would be about $5 billion. This estimate is for the Federal Government only and does not include the exemptions given by many States. Thus, between 1987 and 1995, the Federal Government could save approximately $4 billion from expanded ethanol production. However, if the analysis is continued to the year 2000, the tax losses from exemption of ethanol exceed the gains from lower commodity payments, and cumulative tax losses from 1987 to 2000 exceed the cumulative commodity program gains over that time (51,52).

Rural Development—The ethanol industry will contribute to rural development mainly through the construction and operation of ethanol production plants. It is difficult to estimate precisely what the impact will be. Ethanol production is not labor-intensive; large plants employ approximately 50 to 150 permanent workers. It is estimated that expansion of ethanol production to the 3-billion-gallon level could potentially directly employ an additional 3,000 to 9,000 workers. Additional community jobs to provide services could be of the same magnitude (51,52).

Environmental Impacts—Using ethanol in fuel blends and as an octane enhancer could help reduce carbon monoxide (CO) levels in the atmosphere, and potentially increases hydrocarbon emissions (51,52). Additionally, increasing prices for corn will cause farmers in the Corn Belt to switch acreage from soybean production to corn production. Corn is a fairly chemical-intensive crop, so there may be groundwater contamination issues to consider, as well as the impacts from a potential increase in monoculture production in this region.

Due to the complexity and extent of interaction among agricultural commodity markets, developing a new use for one commodity can have significant, and perhaps unexpected impacts on other commodities. Because different crops predominate in different geographical regions of the United States, there could be significant interregional impacts.

Potential candidates (other than those derived from corn starch) for petroleum replacement are the fatty acids and resins discussed in this report. Opportunities for vegetable oils to replace linear alcohols and olefins derived from petrochemicals (e.g., ethylene and propylene) depend on improved yields of olefins from oils, and the development of new products in the detergent (12 to 18 carbon range) and the plasticizer (6 to 10 carbon) ranges. Also important is the potential of biomass-derived glycerin to replace petrochemically derived glycerin, because the first step in preparation of fatty alcohols and olefins involves the conversion of triglycerides to methyl ester and glycerin (22). The extent to which petroleum replacement has already occurred and the potential for further replacement needs additional analysis, but industry trends and expectations can be discussed for some industries.

Detergent Industry

Vegetable oils (coconut and palm kernel) and petroleum-derived ethylene can be used to produce linear alkylate and alcohol surfactants, chemicals used in the production of soaps and detergents. Global production and percent of linear alkylate surfactants made from natural oils is expected to increase by 1995 (table 3-16).

The use of vegetable oils might be constrained by the fact that synthetic chemicals are used in the conversion process. The development of two new classes of surfactants, glycosides and alpha-sulfomethyl esters, may present new possibilities for vegetable oil uses (14). The new crop *Cuphea* could potentially replace ethylene and tropical oil uses.

Rubber Industry

In 1989, the United States consumed 6.6 billion pounds of rubber, 30 percent of which was natural rubber. Of the total rubber consumed in the United States in 1989, 60 percent was used in tires. Approximately 89 percent of the tires manufactured were radials which use a higher natural-rubber-to-synthetic-rubber ratio than non-radial tires. World rubber production in 1990 is expected to be about 25 billion pounds, 37 percent of which is natural rubber (45). World demand for rubber is expected to increase for the next several years (table 3-17). Development and market inroads of high-performance, low-profile tires would increase rubber demand in the United States because these tires are bigger, use more rubber, and wear out faster than radials (45). The new crop quayule could potentially replace natural and synthetic rubber uses.

Paints and Coatings Industry

Fifty percent (532 million gallons) of paints used in the United States are architectural paints. To meet volatile-organic-emission standards, the industry has developed high-solids and latex-based paints to replace traditional petroleum-derived solvents in paints. However, about 325 million gallons of alkyld resin paints are still produced in the United States each year. *Vernonia* has potential to replace the solvents used in these paints (38).

Many commodity chemicals that can be obtained from petroleum or agricultural commodities, can also be obtained by coal gasification and natural gas conversion. Relative prices and environmental regulations will be important factors in determining the source. Currently, about 8 percent of the U.S. consumption of natural gas is for the production of chemicals (10). Coal can be relatively easily incorporated into the petroleum processing system, and several petroleum companies control large coal reserves. Additionally, research is being conducted to utilize lignocellulose (e.g., wood) to produce many chemicals that can be derived from fermenting cornstarch. Linear programming studies assessing the potential of using chemicals derived from plants in place of petroleum indicate that, in the abscence of petroleum and natural gas, coal would likely be used before biomass. Additionally, of the biomass sources available, wood is more attractive than corn starch (10). The impact that this development might have on farmers will depend on whether farmers grow woody or forage crops to supply the lignocellulose, or whether it is derived from waste products of the paper and lumber industries and from recycling.

Table 3-16—Expected Global Production Capacity of Surfactant Alcohols (billion lbs)

	1990	1995
Linear alkylates/alcohols	2.9	3.6
Percent ethylene derived ..	61	51
Percent natural oil derived .	39	49

SOURCE: Bruce F. Greek, "Detergent Industry Ponders Products for New Decade," *Chemical and Engineering News*, Jan. 29, 1990, pp. 37-60.

Table 3-17—Expected World Rubber Demand Trends

	Estimated percent per annum growth in rubber demand 1990-94
Asia, Oceania, Latin America	2.7
North America, Europe, Africa, Middle East	1.5
Centrally Planned Economies	3.1

SOURCE: Stephen Stinson, "Rubber Chemicals Industry Strong, Slowly Growing Despite Changes," *Chemical and Engineering News*, May 21, 1990, pp. 45-66.

Substitution of agricultural chemicals for petroleum will not result in a one-to-one reduction of petroleum uses. Growing crops takes energy and chemicals, many of which are derived from petroleum. Chemical conversion of agricultural commodities is often energy-intensive. As noted earlier, the extent of petroleum replacement will depend on this net energy balance. A full assessment of the potential of agricultural commodity chemicals to replace petroleum-derived chemicals would need to consider this.

Full Utilization of Land Resources

New uses of traditional crops and new crops could potentially lead to the full utilization of productive land that is currently left idle or planted to trees and grasses. Studies indicate that the United States could relatively easily plant 400 million acres in crops, and under extremely high demand conditions, could potentially cultivate an additional 100 to 140 million acres. Some of this land is planted to pasture used for livestock grazing. Some is held in small or fragmented holdings and faces competition from nonagricultural uses; conversion to crop production will be relatively expensive and expected returns need to be high enough to offset the conversion costs (4,44). Additionally, much of the land removed from crop production is fragile and subject to soil erosion. Through 1990, 33.9 million acres of land had been enrolled in the Conservation Reserve Program[15] (50,56). If these acres are to be returned to crop production, extreme care in crop selection will be needed.

The acreage required[16] to grow crops that would significantly reduce U.S. petroleum fuel use would be substantial (table 3-18). To replace U.S. petroleum-derived ethylene with cornstarch-derived ethylene, would require production of approximately 27 million acres of corn.[17] Current U.S. production levels of ethanol from cornstarch replace no more than 1 percent of the gasoline used in the United States. Using soybeans to replace just the agricultural uses of diesel fuel would require increasing soybean production by nearly 10 million acres over current production levels.[18] Using crops such as sunflowers or the new crop rapeseed, which produce substantially higher levels of oil per acre than soybeans, would decrease the acreage needed, but even so, a significant portion of U.S. crop acreage would need to be devoted to fuel production.

Table 3-18—Estimated Acreage Needed To Supply One Billion Gallons of Fuel[a]

Crop	Fuel replaced	Acreage
Soybeans	Diesel	22 million
Sunflowers	Diesel	16 million
Rapeseed	Diesel	8 million
Ethanol	Gasoline	3.5 million

[a] To estimate petroleum replacement, calculations must be estimated on an energy basis rather than a volume basis (vegetable oils and ethanol have a lower energy content than diesel fuel and gasoline respectively, and would therefore require a greater volume to achieve the same energy content) and energy requirements needed to grow and process the agricultural commodities need to be considered. Agricultural commodity yields were assumed to be the U.S. average, 1984-88.

SOURCE: Office of Technology Assessment, 1991.

Table 3-19—Estimated Acreage Requirements for Selected New Crops To Replace Imports[a]

New crop	Imported crop	Estimated acreage (million of acres)
Cuphea	Coconut oil	1.40
Cuphea	Palm kernel oil	0.56
Lesquerella	Castor oil	0.33
Stokes aster	Converted soybean oil	0.49
Vernonia	Converted soybean oil	0.68
Crambe	Rapeseed oil	0.29
Rapeseed	Rapeseed oil	0.24
Guayule	*Hevea* rubber	3.60
Kenaf	Newsprint	1.00
Soybean oil	Printing inks	1.01

[a] Estimations were based on 1987 levels of U.S. imports and yields of new crops obtained in experimental plots. Calculations involving oilseeds are based on fatty acid equivalents.

SOURCE: Office of Technology Assessment, 1991.

Crop acreage needed to supply total demand for commodities which would substitute for those currently imported (i.e., oils and resins), will be determined by domestic demand and export potential. A rough approximation needed to satisfy current U.S. demand can be made (table 3-19). Calculations are based on *current* imports of oils, resins, and fibers for which the new crops could substitute, and include demand for both food and nonfood uses.[19] Hence, some calculations may overestimate the acreage needed to satisfy industrial uses. Acreage needs may also be overstated because yields of new crops are based on levels currently obtainable, not necessarily those that would be needed for economic viability.[20] (See app. D, table D-1 for calculation details.)

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[15] The Conservation Reserve Program removes highly erodible and/or environmentally sensitive cropland from production for a period of 10 years. It is authorized to remove 40 to 45 million acres.

[16] A thorough estimation of acreage needs to displace petroleum-derived fuels using agricultural products would require calculations based on energy content (rather than volume), net energy requirements (energy required for production and processing subtracted), and average crop yields that could be expected if production significantly expanded (rather than current U.S. averages). If these factors were included, acreage requirements would likely be greater than those estimated.

[17] This calculation assumes that 34 pounds of starch can be obtained from a bushel of corn, and 3 pounds of starch are required to produce 1 pound of ethylene.

[18] The United States annually consumes approximately 40 billion gallons of diesel fuel, and about 3 billion gallons are used in the agricultural sector.

[19] Calculations for soybean inks are based on current U.S. use of 400 million pounds of printing inks (*Science of Food and Agriculture*, "Soybean Oil Inks," vol. 2, No. 2, July 1990).

[20] To be economically competitive, many new crops will require higher yields per acre than are now obtained in experimental plots. Higher yields per acre mean fewer acres are needed to produce the output. For example, currently obtainable guayule yields (500 lbs/ac) are less than the 1,200 lbs/ac estimated to be needed for economic competitiveness.

Rough calculations of U.S. acreage needed to replace current world production levels for some of these imported agricultural commodities can approximate export potential (table 3-20).

These estimates represent upper levels based on *current* world demand. Total acreage needs would depend on the potential to expand demand for these commodities beyond current levels, and the ability of the new crops to capture a significant percentage of the world market share. One would not expect U.S. production of new crops to displace world production completely. New crops will, in many cases, be substitutes for these imported crops and, therefore, they will compete with each other for many of the same markets. Large supply increases (without sufficient demand increases) will decrease the price of all substitutes and affect the production levels and market share of all substitute commodities.

Increasing global capacity to produce, process and manufacture products from agricultural commodities will affect the potential for U.S. exports of these products. Other countries (e.g., Argentina and Brazil for soybeans and Canada and the European Community for edible quality rapeseed) have demonstrated a capacity to increase production in response to favorable prices. Guayule can readily be grown in Mexico. Supply of lauric acid oils is expected to increase to 7.1 million tons by the year 2000 (i.e., 3.7 million tons of coconut oil and 3.4 million tons of palm kernel oil), due primarily to the maturation of high yielding palm trees planted in Asia (1,14). The International Agricultural Research System and multinational seed companies are increasing the ability to rapidly transfer and adapt new seed varieties to many countries in the world (35).

Developing and newly industrialized countries are increasing their capability to produce products from agricultural commodities for their own domestic use, and in some cases are beginning to capture market share in world markets. For example, most of the new capacity to produce natural oil surfactants has been built in Third-World or newly industrialized nations; the industry has overcapacity, and is still expanding. Prior to 1986, U.S. producers supplied the linear alkylate and alcohol surfactant demand in the United States and Canada. Now, 5 to 10 percent is supplied by imports from Western Europe and Third World nations (14). Analysis of the U.S. potential to capture market share for both raw and processed products derived from agricultural commodities is needed.

Table 3-20—Estimated Acreage Needed To Replace World Supplies

Imported crop	New crop	World production (million lbs.)	Acres needed (millions)
Coconut[a]	Cuphea	2.77	7.6
Palm kernel[a] ..	Cuphea	1.48	4.5
Rubber[b]	Guayule	9,250	18.5
Castor[c]	Lesquerella	1,705	1.1
Newsprint[d]	Kenaf	33[a]	4.7

[a] World production levels are 1989/1990 preliminary estimates of coconut and palm kernel oil in million metric tons. Acreage calculations based on acres needed to obtain an equivalent amount of lauric acid as would be obtained from the coconut and palm kernel oil. Source: U.S. Department of Agriculture, Foreign Agricultural Service, *World Oilseed Situation and Outlook*, November 1990.

[b] World production level is in million pounds and is based on 1990 estimates of world rubber production of 25 billion pounds, 37 percent of which is natural rubber. Source: Stephen Stinson, "Rubber Chemicals Industry Strong, Slowly Growing Despitee Changes," *Chemical and Engineering News*, May 21, 1990, pp. 45-66.

[c] World production level is in million pounds of castor beans, and is based on 1984 to 1986 production of selected countries (including Brazil and India). Calculation is based on pounds of Lesquerella seed needed to replace castor beans. Source: U.S. Department of Agriculture, Economic Research Service, "World Indices of Agricultural and Food Production, 1977-86," March 1988.

[d] World production is in million tons and based on U.S. consumption of 12.3 million metric tons being 41 percent of world consumption. Source: Fred D. Iannazzi, "The Economics Are Right for U.S. Mills To Recycle Old Newspapers, *Resource Recycling*, July 1989, p. 34.

SOURCE: Office of Technology Assessment, 1991.

Future increases in recycling efforts may also affect virgin commodity needs. For example, in 1987 the United States consumed approximately 12.3 million metric tons of newsprint (41 percent of world consumption). Approximately 32 percent is recycled. Of the newsprint manufactured in the United States, 24 percent of the fiber used is from recycled newsprint while 76 percent is virgin fiber. Newsprint made from 100 percent recycled newsprint is generally of lower quality than that made with virgin fiber, but room exists for significant increases in recycled newsprint, which could reduce the use of virgin fibers for this use (18). Some studies indicate that mixing kenaf with recycled newspaper pulp improves the strength and brightness of the recycled paper; the role that kenaf could play in recycling needs further study.

Determination of the acreage needed to produce agricultural crops for industrial uses has implications for the U.S. Gross National Product (GNP) which would be affected by additional production and use of idled resources. Replacing imports with domestic production could increase U.S. income.

The average value of U.S. vegetable oil imports[21] for the fiscal years 1986 through 1988, was $591 million per year. The value of U.S. imports of rubber and gums for the same time period was approximately $759 million per year (58). Annual U.S. imports of newsprint are valued at approximately $4.5 billion (11).

Additional impacts could result from value added in the agricultural sector. The agricultural sector consists of the farm sector, upstream activities related to farming (i.e., firms that supply agricultural inputs and services) and downstream activities (i.e., firms engaged in the storage, processing, transport, manufacturing, distribution, retailing, consumption, and export of agricultural products). The food and fiber system accounts for about 18 percent of the U.S. GNP; farming accounts for 2 percent, upstream activities account for about 2 percent, and the remaining 14 percent results from the downstream activies (16,21). Currently, excess capacity exists in the farm sector and many of the downstream activities. This implies that the impacts of small changes in price and production volume would be limited to the farm sector. Changes in upstream activities occur at higher prices and volumes than in the farm sector, and downstream activities require highest levels of change.

Ultimately however, it is necessary to decide whether using all excess capacity is wise or whether it is better to maintain some excess capacity. Recent dry weather has reduced surplus stocks to minimum levels. Rebuilding stocks will require planting additional acreage. Without some excess capacity, the ability to respond to factors beyond our control would be hampered. Maintaining at least some excess production capacity may provide a measure of food security.

Premature Commercialization

Premature commercialization of new industrial agricultural products can indefinately delay successful marketing. The development of degradable plastics to alleviate solid waste and litter problems illustrates this point. In the early stages, environmentalists supported these products for some specific uses, such as six-pack beverage rings. However, as product types and claims of effectiveness multiplied, criticism emerged. The products were marketed without a clear definition of, or standards for, degradability. Lawsuits have been filed against some manufacturers of these products for false and misleading advertising. Additionally there have been calls for an end of public sector research on these products, and some states have considered legislation banning their use. Potential markets for degradable plastics are estimated to be declining. Apparently, research for second-generation degradable plastics has been continuing, but confusion and doubts about the appropriateness of these technologies remain with the public and environmental community. It remains to be seen what effect these doubts will have on future efforts to market degradable plastic products (46,49).

Triticale, a wheat-rye hybrid that is high in protein, is an example of a new crop that was introduced (in the 1950s) without clearly establishing its market. From the beginning, triticale was viewed as another wheat, even though its processing qualities were different from wheat and it could not directly substitute for wheat. This problem, combined with yields that were lower than wheat, lead to the foundering of triticale as a new grain crop. Today, triticale is grown in the United States in small quantities, primarily as a forage crop in the Southeast, with some use in specialty baking products (19).

It is enticing to try to commercialize a product as quickly as possible to obtain any potential benefits the product might yield, and unnecessary delays should be avoided. However, commercializing a new crop or product prematurely risks destroying the potential of that new product. A clear marketing strategy that analyzes potential problems is needed.

Summary and Conclusions

The lack of studies evaluating the potential impacts of new industrial crops and uses of traditional crops precludes making definitive statements on what these impacts will be. This chapter is a preliminary attempt to analyze potential impacts, but more detailed analysis is needed. Based on this initial analysis, several conclusions are suggested.

Examination of rural employment impacts during the 1970s when agricultural production rapidly expanded, suggest that development of new crops and uses may result in modest rural employment growth in agriculturally related industries. Agriculturally dependent communities would be most affected. However, the majority of the agriculturally related jobs created are likely to be located in metropolitan, rather than rural communities. Additionally, many of the industries that will use chemicals derived from agricultural commodities are already located in metropolitan areas, and in several cases, may require highly skilled labor. Location of new manufacturing facilities in many rural areas will be difficult to achieve.

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[21] Vegetable oils imported include palm, palm kernel, coconut, olive, rapeseed, castor, tung, and linseed oils.

Development of new industrial crops and uses of traditional crops does have the potential to provide a domestic source of strategic and essential industrial materials. Technically, biomass-derived chemicals could also potentially replace many petroleum-derived chemicals. The major constraint is economics. The chemical industry is highly integrated, flexible, and has large economies of scale. Penetration of many of these markets is difficult. Additionally, some of these markets are large (i.e. fuel and primary chemical feedstocks) and significant replacement would use millions of acres of cropland, have far-reaching environmental implications, and could significantly increase food prices.

The benefits of new technologies are captured by those who first adopt the technology. A strong correlation exists between early adoption and size of farm enterprise. It is likely that operators of large farms will adopt new crops before operators of small farms and, therefore, capture these benefits. For traditional crops covered by Federal commodity programs, market prices must increase enough to exceed price support levels to have a large impact on farm income. The extent to which small farm operators are enrolled in commodity programs will determine how changing market prices affect their income levels. Programs that help small farm operators become early adopters of new technologies will improve the chances of these farmers benefitting from new industrial crops and uses of traditional crops.

The development and production of new industrial crops and uses in the United States could, in some cases, replace major exports of some developing nations, some of which are considered to be of strategic importance to the United States. Additionally, attempts to increase exports of some of the products has the potential to increase trade frictions between the United States and the European Community.

The United States currently has excess agricultural production capacity. Large scale replacement of U.S. fuel use or primary chemical feedstocks would require significant acreage for crop production, however, economics do not favor these developments at the current time. Use of agriculturally derived chemicals to replace some of the oils and resins currently imported is not likely to reduce excess agricultural capacity significantly given current demand and supply conditions.

The ability of new crops to reduce Federal commodity payments will depend on whether or not acreage is shifted from production of crops that are federally supported to those that are not. New uses of traditional crops that are supported, will reduce commodity payments if the new use is not itself subsidized.

Development of new industrial crops and uses of traditional crops will have many environmental impacts, some positive, and some negative. Potentially, new fuels could improve air quality. New crops that are better adapted to their environments potentially could reduce erosion and demand for irrigation. However, many new crops are not native to the United States and problems can and do arise from the introduction of new species. Additionally, many of the crops may be genetically engineered; several environmental issues are raised by this possibility.

As with any new technology, there will be winners and losers. Many new industrial crops and uses of traditional crops potentially will compete with traditional crops. Improved understanding of these impacts is needed.

The lack of studies evaluating the potential impacts of new industrial crops and uses of traditional crops points to the need to fund social science research in addition to the physical, chemical, and biological research. Interdisciplinary research can provide insights into the likely effects that will result from the development of these new technologies, as well as factors that affect the development of the technologies themselves.

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Chapter 4

Factors That Affect Research, Development, and Commercialization

While the development of new industrial crops and uses of traditional crops potentially could benefit society, such development is not a simple matter. It involves technical change, the complex process by which economies change over time with respect to the products produced, and the processes used to produce them (22). New ideas, models, products, and processes must be conceptualized and research conducted to develop promising products and processes for commercial use. New processes and products must be adopted by firms and spread throughout an industry to achieve maximum impacts. Governments can affect the rate of technical change by influencing the general economic environment (fiscal and monetary policy as well as regulatory policy can enhance or inhibit technical change), and by specific policies designed to encourage technical change.

U.S. technical policy focuses predominantly on the research to develop new ideas. Federal and State governments, and the private sector, have numerous programs and provide billions of dollars to support such research. Commercialization is generally the responsibility of the private sector, although the Federal and State Governments have passed legislation and developed some programs to encourage technology transfer from public-sector research to the private sector. Many of these programs are of recent origin and have limited funding. The process of adoption of new technologies, with a few notable exceptions, receives little public-sector attention.

For new industrial crops and uses of traditional crops to be commercialized, many technical and economic constraints must be overcome. Involvement of the public and private sectors is needed. The extent of this involvement, and the speed at which new technologies will be developed and commercialized will be influenced by many factors. This chapter analyzes many of these factors, and describes some Federal and State programs available to encourage the research, development, and commercialization of new technologies. Chapter 5 will discuss important factors involved in the adoption of new technologies.

Research and Development

It is one of the myths of technical change that the process proceeds in a linear manner from basic to applied research, to development, to marketing, and to dissemination. In fact, a more accurate description might be one where science- and technology-oriented research follow two parallel but interacting paths. The two paths are connected by a common pool of scientific knowledge that feeds and draws from each research path. While personal insight, professional curiosity, and the state of the science all play a role, the speed and direction of technical change is highly influenced by the interaction of economic and institutional factors.

Private-sector research and development is motivated by profit-seeking and will tend to occur whenever profit and risk conditions create comparatively attractive investment opportunities. Firms undertake research and development to reduce the unit costs of production (generally through process development), and/or to stimulate demand for outputs (new product development). Firms develop new processes to reduce the use of production inputs that are, in the future, expected to become relatively more expensive than other inputs (i.e., firms minimize the present discounted value of expected future costs). The resources allocated to a particular line of research will also be influenced by the cost and productivity of the research. New product research resources are usually concentrated on products that are expected to have the highest prices and largest markets, and development efforts are accelerated for such new products. Development activities are slower for new products that substitute for existing, profitable products (2,10,22,24).

Public-sector research can be active or passive. The public sector, in response to actual, anticipated, or perceived needs, can take an active stance by setting its own research priorities and providing adequate resources to meet established goals. The public sector can take a passive approach by following the research priority agenda determined by interest groups. Interest groups demand public-sector funding for research that they believe will bring a payoff to themselves. They commit their own resources in a similar fashion. Federal fiscal constraints tend to reinforce the passive approach to public research by intensifying the search by scientists and research administrators for private research monies and competitive grants (16).

With the possible exceptions of guayule and ethanol derived from cornstarch, Federal policy concerning new industrial crop and use development has been relatively passive. Interest groups, for the most part, have not demanded this type of public-sector research, and the private sector has not invested in public-sector research of this type. The private sector has shown interest in new industrial crops and uses that have relatively clear potential to substitute for inputs whose cost is increasing (relative to the cost of other inputs), or whose market is affected by regulation. Situations where these factors are not so obvious have not elicited substantial private-sector interest.

The new industrial crops *Vernonia* and *Cuphea* illustrate these points. Lauric-acid containing oils (coconut and palm kernel oil) and petroleum-derived ethylene can be used to produced surfactants for use in detergents, emulsifiers, and wetting agents. The new crop *Cuphea* also produces oil containing lauric acid, and could be used in place of coconut and palm kernel oil or ethylene in many detergents. Raw material costs in the detergent industry are a small portion of total product cost and have little impact on profitability. Additionally, supplies of coconut and palm kernel oil are expected to at least double within the next decade as recently planted, high-yielding palms begin to mature (1,7). The detergent industry provides limited funding for *Cuphea*. Industry interest in developing *Vernonia* is increasing. Stricter volatile organic emission standards are forcing the reformulation of many paints and coatings. Preliminary results show that use of *Vernonia* oil as a diluent in place of organic solvents can reduce volatile emissions. The paint and coatings industry is increasing its support for research on *Vernonia* (19).

Industrial Use Research Funding and Institutional Involvement

The Federal institution most involved in agricultural research is the U.S. Department of Agriculture (USDA). Research funds are allocated through the Cooperative State Research Service (CSRS) and the Agricultural Research Service (ARS). Research funds awarded to the State Agricultural Experiment Stations located within the Land Grant Universities are administered through CSRS. Funding includes formula funds (Hatch, Evans-Allen, McIntyre-Stennis, Animal Health, etc.), special grants, education and facilities grants, and competitive grants. Total CSRS funding to the State Experiment Stations for fiscal year 1990 was approximately $344 million. It is estimated that approximately $5 million is allocated to research and development of new crops and uses of traditional crops ($2 million for new crop research and $3 million for new use research) (12). Universities have performed most of the agronomic research and some utilization research on new crops and industrial uses.

The fiscal year 1990 budget for the ARS was approximately $609 million. Of this amount, it is estimated that expenditures for industrial-use research were $15.5 million. Much of this funding, however, focused on more traditional uses of cotton fibers and not new uses. An estimated $2.7 million was allocated to new crop research. Additionally, another $6.7 million was spent on research that could indirectly enhance industrial uses (12,17). The primary ARS center for research on new crops and industrial uses is the Northern Regional Research Center in Peoria, Illinois, which focuses primarily on utilization research.

The Critical Agricultural Materials Act established the Office of Critical Materials (OCM) located within USDA. This office serves as "a central location where USDA can address research and development with respect to agricultural crops that have the potential of producing critical materials for strategic and industrial purposes." A Joint Commission on Research and Development of Critical Agricultural Materials, which includes representatives from the Department of Agriculture, the Department of Commerce, the Bureau of Indian Affairs, the National Science Foundation, the Department of State, the Department of Defense, and the Federal Emergency Management Agency, oversees the activities of the Office of Critical Materials. This office is trying to commercialize many of the new industrial crops discussed in this report. Commercialization efforts have been greatest for guayule, kenaf, jojoba, *Crambe*, and industrial rapeseed. Some efforts have been made to commercialize meadowfoam and *Lesquerella*. The 1990 Farm Bill reauthorized the Critical Agricultural

Materials Act through FY 1995, and Congress appropriated $1,968,000 for FY 1991 to fund research on guayule ($668,000), *Crambe* and rapeseed ($500,000), and other unspecified research ($800,000).

In addition to ARS and CSRS activities, other USDA agencies such as the Forest Service also support research on industrial uses of forest products. Other Federal agencies such as the Department of Defense (DoD), the Department of Commerce, the Department of Energy, the National Science Foundation, and the Agency for International Development provide some funding for industrial uses of agricultural commodities. The States, as well as the private sector also provide some funding, as do commodity organizations, such as the National and State Corn Growers Associations.

Funding Levels for Specific New Crops and Industrial Uses

USDA expenditures for selected new crops for fiscal year 1989 are summarized in table 4-1. To put these funding levels in perspective, USDA and the State Agricultural Experiment stations annually spend, on average, an estimated $120 million for corn, wheat, and soybean research.

The $325,000 being spent by USDA on *Crambe* and winter rapeseed supports an eight State consortium that is attempting to commercialize these two crops. The eight States involved are Missouri, Kansas, New Mexico, Idaho, Iowa, Nebraska, North Dakota, and Illinois. It is estimated that these States are receiving an additional $2 in State support for every $1 of Federal support (12).

Guayule is the new crop most heavily supported, as mandated by the Native Latex Act and later the Critical Agricultural Materials Act. Much of the funding has come from DoD and USDA. Table 4-2 summarizes known expenditures for guayule development. Private-sector expenditures on guayule research are estimated to be three to four times USDA levels (12).

Kenaf is also receiving public- and private-sector attention. The Joint Kenaf Task Force (JKTF) composed of Kenaf International, CIP Inc., and Combustion Engineering's Sprout-Bauer Division, in cooperation with USDA, is attempting to commercialize kenaf. The program consists of three phases. Phase I, begun in 1986, involved agronomic and papermaking research. Phase II, begun in 1987, focused on commercial trials. Phase III, currently in progress, is focusing on agronomic and utilization research. Table 4-3 summarizes expenditures for kenaf research. It is estimated that private-sector support is three to four times the USDA expenditures (3,11,12).

Table 4-1—USDA Fiscal Year 1989 Expenditures for Selected New Crops (dollars)

Crop	Amount
Cuphea	$ 100,000
Meadowfoam	350,000
Lesquerella	20,000
Crambe/rapeseed	325,000
Guayule	1,168,000
Kenaf	675,000
Total	2,638,000

SOURCE: Office of Critical Materials, U.S. Department of Agriculture Cooperative State Research Service, 1990.

Table 4-2—Expenditures for Guayule Research (millions of dollars)

Year	Amount	Agency
1978-86	$13.1	Department of Defense
	13.2	U.S. Department of Agriculture
	2.9	Other Federal
	2.7	Firestone Tire & Rubber
1987-88	15.0	Department of Defense
	4.3	U.S. Department of Agriculture
1989	1.168	U.S. Department of Agriculture
1989-96 estimated	38.0	

SOURCE: Office of Critical Materials, U.S. Department of Agriculture Cooperative State Research Service, 1990.

The California South Coast Air Quality Management District, the State of Michigan, the U.S. Agency for International Development, and Paint Research Associates (an industry-financed research group) have committed $425,000 for *Vernonia* research (19). The Tennessee Valley Authority, in cooperation with the Department of Energy, conducts research on the conversion of lignocellulose to chemicals. Funding levels for other crops are unavailable, but the amounts seem to be small. (See *Appendix A: Selected New Industrial Crops* for more specific information concerning each individual crop.)

Research and development of new uses for traditional crops is also conducted by the public and private sectors. The General Accounting Office has evaluated the extent of Federal support for degradable plastic research (28). Their findings for fiscal year 1988 are summarized in table 4-4. Several private firms are also interested in degradable

Table 4-3—Expenditures for Kenaf Research (dollars)

Research	Amount	Agency
Phase I	141,000	U.S. Department of Agriculture
	263,000	Joint Kenaf Task Force
Phase II	300,000	U.S. Department of Agriculture
	644,000	Joint Kenaf Task Force
Phase III	675,000	U.S. Department of Agriculture

SOURCE: Office of Critical Materials, U.S. Department of Agriculture Cooperative State Research Service, 1990.

Table 4-4—1988 Federal Expenditures for Degradable Plastic Research

Agency	No. of projects	Funding
U.S. Department of Agriculture . .	4	$ 941,000
Department of Defense	4	575,000
Department of Energy	3	150,000
National Science Foundation	1	63,000
Total	12	$1,729,000

SOURCE: U.S. Congress, General Accounting Office, "Degradable Plastics: Standards, Research and Development," RCED-88-208 (Gaithersburg, MD: September 1988).

plastics, and have products on the market, many of which use cornstarch.

Funding for ethanol desulfurization of coal has been provided by the Illinois State Geological Society, Southern Illinois University-Carbondale, Illinois Department of Energy and Natural Resources, the Illinois and Ohio Corn Marketing Boards, and the U.S. Department of Energy. Expenditures of approximately $2.85 million have been allocated for 1987 through 1991 (33).

Funding levels for other uses are unavailable. (See *Appendix B: Selected New Industrial Uses for Traditional Crops* for more specific information on each use.) In addition to the United States, other countries have expressed interest in developing new industrial crops and uses for traditional crops. For example, Japan is currently in the second year of a 7-year, $100 million program to develop degradable plastics (21). The European Community has also begun funding a program to develop new industrial crops and uses of traditional crops (box 4-A).

Commercialization

New products and processes developed in Federal laboratories or universities will not be in the form of a fully developed, marketable product. Commercialization will require considerable research and development effort on the part of companies. For new crops and uses, commercial-scale extraction, separation, purification, and chemical transformation mechanisms that are economically competitive will need to be developed. For chemicals used in strategic applications, reliability and performance characteristics will be of paramount importance. Consistent quality control procedures must be developed, and for many uses, performance standards must be established. In some situations, waste disposal procedures must be developed. Commercialization efforts by private firms will follow their research and development efforts and will be driven by the same economic factors.

Cooperation and technology transfer between the public and private sectors will be a key component of the commercialization effort. Technology transfer is the process by which technology, knowledge, and/or information developed in one organization, in one area, or for one purpose is applied and used in another organization, in another area, or for another purpose. Technology transfer can include the transfer of legal rights and the informal movement of information, knowledge, and skills. Private-sector awareness, interest, and capacity to utilize public-sector research effectively will be critical to the successful commercialization of new uses of agricultural commodities.

Industrial Interest in Public-Sector Research

A critical component of technology transfer is the interest of industry, without which institutions to transfer technology will be ineffective. Industrial interest has frequently been lacking in the past; industries have not wanted to use technologies not developed in their own laboratories (29). Industry has felt that it can get little value from cooperative agreements and has not encouraged them. Small firms have often felt that this is a big company game that they are ill-equipped to play (13). These attitudes may be changing, primarily because of industry's need to respond to rapidly changing markets, and because of legislation that has made licensing and collaborative R&D with Federal laboratories easier (23).

Economics will play a major role in the private-sector demand for technology developed in the public sector. Many new crops being developed are intended to substitute for chemicals that are currently either imported or derived from petroleum, and which may be widely accepted and available. It is unlikely that any single company will commit

Box 4-A—European Research Program To Develop New Industrial Crops and Uses of Traditional Crops

In addition to the United States, the European Community (EC) is exploring alternative crops and uses as a means of alleviating their agricultural problems. The EC has initiated a program called the European Collaborative Linkage of Agriculture and Industry Through Research (ECLAIR), to improve the interface between industry and agriculture. ECLAIR is being administered through the Science, Research and Development Directorate. ECLAIR has been funded for $80 million over 3 years. All grants require matching funds from an industrial partner. Awards are decided on a peer-reviewed basis. The program is divided into four sectors:

1. Production of Biological Resources, which includes many agronomic features;
2. Harvesting and Conditioning, which includes transportation, classification, and storage;
3. Fractionation and/or Extraction; and
4. Methods of Transformation and their control.

Preference will be given to large, interdisciplinary projects, to proposals utilizing advanced technologies such as biotechnology, to projects that potentially can improve the competitiveness of European agriculture and/or have positive environmental impacts (Other social goals are not explicitly considered, unlike U.S. proposals that place heavy emphasis on technology applicability to small-scale farms and potential rural job creation) (5). The ECLAIR program requires projects to involve participants from at least two member countries. U.S. proposals can accommodate multidisciplinary, regional projects, but these are not explicit requirements. Like the U.S. proposals, the ECLAIR program requires matching funds from the industrial partner, and is peer-reviewed.

The ECLAIR program, unlike U.S. proposals, does not attempt to commercialize products. It is designed to carry out research necessary before commercialization can be contemplated, and focuses strictly on precompetitive research and development. Precompetitive research is considered to be beyond the stage of basic research, but the results of the research will still require further development to be marketable.

Commercialization will be attempted in another program currently in the planning stages. Current projections for this commercialization program are about $160 million for 3 to 4 years. Additionally, each member country of the EC carries out its own agricultural research and some funds may be available for alternative crops through each country's research (15).

Interest has been shown in Europe for utilizing crops for fuel production and for industrial uses. Crops for which some interest has been expressed include jojoba, *Crambe*, *Lesquerella*, *Cuphea*, *Euphorbia*, sunflowers, *Vernonia*, and *Stokesia* (18). A sister program called FLAIR (Food-Linked Agro-Industrial Research) focuses on food technologies; there are no U.S. proposals to develop new food uses.

resources to develop new alternative supplies in anticipation of future hypothetical shortages (30). This may be particularly true for development of renewable resources, which vary frequently and widely in price and supply.

Economic factors that will affect private-sector interest in using agricultural commodities as inputs include price, quality, performance, and reliability of supply. Price is determined largely by the current and expected trends in supply and demand, the number of substitutes available, transportation, processing, and storage costs, and exchange rates for internationally traded products. Short-run supplies are most affected by environmental or political factors, such as adverse weather, embargoes and commodity cartels. Long-run supply trends are affected by technological change and institutional factors (e.g., Federal agricultural programs), and the quality, price, and quantity of the resources (primarily land and labor) needed to produce the commodities (27).

Demand for agricultural products results from food and feed, industrial, and on-farm uses. Crops that have multiple uses for primary products and byproducts will have more marketing options. Demand for commodities will be highly price sensitive if numerous substitutes are available. Proximity of crop production locations to processing plants, distance of processing plants to markets, method of transport (i.e., air, land, or water), and special transport requirements will affect transportation costs. Processing costs will be affected by techniques used, purification requirements, waste disposal, and volume. Frequently there are returns to scale in the processing of agricultural commodities, which leads to lower per-unit processing costs for high-volume commodities. Fiscal and monetary policies will affect exchange rates, which in turn, affect the price of imported and exported commodities.

The major production cost for many new uses is the price of the commodity itself. The net cost of using a commodity for industrial uses is the price paid for the commodity minus any credits received for the sale of byproducts. In many cases, increasing the use of an agricultural commodity will increase the price of the raw commodity and decrease the price of the byproducts, effectively raising the cost of using the agricultural commodity (25,31). Demand for food and livestock feed exerts pressure on the price of many commodities, and variability in the commodity and byproduct markets leads to wide price fluctuations. These factors make it difficult for agricultural commodities to be price competitive in many uses. Ethanol derived from cornstarch illustrates these points. In recent years, the net cost of corn (price of corn minus credit for byproducts) has ranged from 10 to 79 cents per gallon of ethanol produced. Additionally, as ethanol production increases, the price of corn increases and the value of the byproducts decreases (oil, protein meals), effectively raising the net cost of using corn for ethanol production (31).

In addition to price, the quality of a commodity will affect its competitiveness. A premium can be expected to be paid for crops that have many useful compounds, or compounds whose chemical structure is such that they yield superior performance relative to chemicals they could replace. Superior performance will be important if costly product or process reformulations are needed to use the new crop, and could improve the attractiveness of a new use, even if it is more expensive. As an example, soybean oil-based printing inks are more expensive than petroleum-based inks but are beginning to capture part of the market, particularly in color printing, because they give better colors and resist rub-off (20).

Reliability of supply is an important consideration for manufacturers. Crops that have few producers, or that are produced in few geographical regions, are more susceptible to supply shocks from weather or political factors. Development of alternative supplies might help to ensure supply availability and reduce price variability. Given a more reliable supply and less price variability, manufacturers may be more willing to increase their use of agricultural commodities as a source of chemicals. An example that illustrates this concept is the use of lauric acid-containing vegetable oils in the detergent industry. Coconut oil and petroleum-derived compounds can be used to manufacture detergents, but because of the high price variability and unreliability of supply of coconut oil, petroleum-derived products have been preferred. The maturation of high-yielding palms that produce palm and palm kernel oil is expected to double world supply of lauric acid oils by 1995. The prospect of a larger and more diversified source of supply and less price variability, has stimulated the detergent industry to increase capacity to utilize natural oils (7). Although, many traditional crops are in surplus and supplies for industrial use are available, supply fluctuations affect the cost of using these crops in industrial applications.

An understanding of these economic factors is essential to any market strategy for new industrial crops and uses of traditional crops. Factors within the production process that are now expensive or that are expected to become expensive relative to other production factors are good candidates for substitution through the development of new processes or products. Other good candidates include production inputs whose supply is highly variable, and products or processes that meet only minimal performance standards. Convenience and quality considerations are particularly pertinent to the development of consumer products. New industrial crops and uses of traditional crops that fill well-defined market needs are those most likely to succeed.

Private-Sector Access to Public-Sector Information

A major obstacle to the transfer of technology is the difficulty of learning about or accessing pertinent information (23). Research that might be of value to industry is conducted in numerous Federal and university laboratories in the United States and in other countries. Keeping up to date on this research is a massive undertaking even for large companies with substantial research budgets. For small firms, it is nearly impossible. Industry ability to access research data on new industrial crops and uses of traditional crops may be a serious constraint because firms that are likely to commercialize the new technologies may not historically have had extensive dealings with the Agricultural Research Service or with university Colleges of Agriculture. Mechanisms that aid in the exchange of information and reduce the time and cost involved in searching for information will enhance the opportunity for technology transfer.

The Federal Laboratory Consortium (FLC), consisting of a small central staff and volunteer representatives from at least 300 Federal labs, functions as a single source of entry for firms into the Federal laboratory system. It promotes communication with industry and shows firms where to go for help on a particular problem within the Federal laboratory system. The FLC also maintains computerized general-purpose databases on technologies of possible interest to industry.[1] In conjunction with groups such as the Industrial Research Institute, the FLC holds Federal laboratory-industry conferences to identify possible areas of collaboration. The number of industry participants has been growing. These conferences, which bring industry and Federal laboratory representatives together, provide economical means for companies to search for technologies that fit their needs. This program is clearly not devoted strictly to the development of industrial crops and uses. However, USDA is a member of the consortium, and this link can serve as a mechanism for firms to find out about ARS research activities (29). The FLC currently receives about $1 million per year, with funding due to expire in fiscal year 1991.[2]

In addition to establishing the Office of Critical Materials, the Critical Agricultural Materials Act also provided for the establishment of a database on industrial crops to be housed in the National Agricultural Library (NAL). The NAL, in cooperation with the Arid Lands Information Center at the University of Arizona, collects published material on industrial crops. Bibliographies of several crops are available. The information is also available through AGRICOLA, the Library's computerized database system relating to agricultural research. The CRIS and TEKTRAN databases also contain information about ARS and university agricultural research (32).

Many universities also have established offices that aid in disseminating research information to industry. These university offices are not devoted exclusively to developing new industrial crops and uses, but can direct interested firms to researchers performing this type of research within the university.

Technology Transfer Mechanisms

Technology transfer between Federal and university laboratories and industry can be facilitated in many ways, including personnel exchange between laboratories and industry, private-firm use of specialized laboratory facilities, and the granting of licenses to firms to commercialize technologies patented by the public sector.

Cooperative agreements between industry and public-sector research institutions are designed to create new technology that the firm can then commercialize, rather than to transfer preexisting technologies. With risk and expense sharing, industry is better able to take on large and long-term projects with uncertain payoffs. These types of arrangements can be difficult because they may require a fundamental reorientation on both sides. Issues of conflicts of interest, fairness to firms, national security, and proprietary information can create obstacles. Nonetheless, collaborative agreements exist between Federal laboratories and industry, and between universities and industry. The cooperative agreements that seem to be most effective are those made at a scientist-to-scientist level, rather than at the administrative level (13).

Incentives for collaboration in Federal laboratories are sometimes weak or even negative. Technology-transfer activities sometimes do not count in a researcher's performance evaluation even though the law specifies that it should. Researchers may view collaborative agreements unattractive if the work is proprietary and cannot be published as the researcher's own. Sabbaticals in industry are often not counted as pensionable. Only recently have researchers and their laboratories been permitted to keep portions of patent royalties for their inventions. It is not possible to copyright material developed in whole or part by government employees (29).

Slow negotiations and delays can cause deals to collapse as a firm's strategic situation changes. Startups are especially vulnerable. Many delays revolve around a company's desire for exclusive rights to help recover the cost of expensive R&D efforts, which may require the Federal laboratory to waive its patent rights. Until recently, industry collaboration has been impeded by the possibility of data and information release under the Freedom of Information Act (FOIA). The National Competitiveness Technology Transfer Act of 1989 largely removed this obstacle by exempting the results of collaborative R&D from release under FOIA for 5 years (29).

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[1] The Federal Research in Progress Database (FEDRIP) contains information on federally funded research projects.

[2] The Consortium is funded by a set-aside of 0.005 percent of the R&D budgets of the Federal laboratories.

Personnel exchange between private- and public-sector researchers is possible; however, it is uncommon for industry researchers to take visiting positions, particularly at Federal laboratories. The reverse is also quite rare. In the place of formal personnel exchange, visitor programs of just a few hours or days can provide an informal technology-transfer mechanism. Such programs provide opportunities for firms to stay in touch with the latest developments, particularly those in the government laboratories (29).

Startup firms are new firms established specifically to commercialize new technologies. The process can be aided by having the parent laboratory grant scientists entrepreneurial leave, with the right to return to old jobs within a stated time. However, this option does have problems, foremost among them the potential for conflicts of interest and brain drain. Some laboratories have established their own corporations to encourage startups, and provide services to entrepreneurs including office and laboratory space and help in forming business plans and incorporation. They also contribute capital in return for a minority interest in the firm (29). Other methods of technology transfer include allowing firms to use a Federal laboratory's specialized facilities and publication of semitechnical brochures to acquaint industry with technologies that may be of interest.

The Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480) and the Federal Technology Transfer Act of 1986 (Public Law 99-502) were enacted to facilitate technology transfer between Federal laboratories and industry. The Stevenson-Wydler Act provided Federal laboratories with a mandate to undertake technology transfer activities, while the Technology Transfer Act created an organizational structure to meet this mandate.

Federal laboratories are allowed to participate in cooperative R&D agreements and to grant exclusive licenses for resulting patents to the private businesses with which they cooperate. Each Federal department with one or more laboratories must allocate at least 0.5 percent of its existing research budget for technology transfer activities; additional funding for these activities was not provided. Identifying technologies with commercial possibilities, patenting, finding firms that might be interested, and exchanging information with those firms takes time, effort, and substantial funding. In some cases, startup firms will require support in the form of office space, help in writing a business plan, access to venture capital, etc.

Successful technology transfer requires a full-time staff, and a sustained financial commitment. Firms may hesitate to pledge themselves to multi-year projects when the government will commit funds only year by year. Given the financial constraints that already exist in many Federal research laboratories, it is perhaps not surprising that progress has been slow (29). However, cooperative agreements between industries and Federal laboratories are occurring. According to the USDA, the Agricultural Research Service has entered into 127 cooperative research and development agreements with industrial firms since 1986, and is in the process of negotiating 34 more agreements (32). Several of these agreements are for the purpose of commercializing new crops or uses of traditional crops.

Financial Assistance

Sometimes firms are interested in developing a new technology or product but the cost of the research and development needed to commercialize the technology exceeds the budget of the firm. This is a particular problem for small firms or startups. Federal and State programs are available to provide financial assistance to small firms.

Small Business Innovation Research Program

The Small Business Development Act was passed in 1982. Part of the Act required all Federal agencies that provide external research funds to establish a Small Business Innovation Research (SBIR) program modeled after a National Science Foundation program begun in 1977. Funding for each agency's SBIR program is equal to 1.25 percent of the agency's total external research funding budget. The total annual SBIR budget is approximately $350 million. Eligibility is restricted to small firms of fewer than 500 employees.

Grants provide funding for research from an idea to a prototype in three phases. Phase I grants are for $50,000 for 6 months and are used to determine technical feasibility, determine that sufficient progress has been made before larger funding takes place, and determine whether the firm can do high-quality research. Phase II involves the principal research. Grants last 1 to 2 years at levels up to $500,000 depending on the agency. Phase I studies accounted for about $109 million in 1987, and phase II accounted for $241 million. Phase III involves finding follow-on private funding to pursue commercial application (SBIR does not fund the final stages of bringing a product to market, but the Small Business Administration does help firms find private financing for commercialization).

USDA is one of the Federal agencies that has an SBIR program. The budget for USDA-SBIR for fiscal year 1989 was approximately $4 million. The USDA-SBIR program is divided into eight topic areas. New crop proposals generally fit into the Plant Production and Protection section. A new section on Industrial Applications has been established for fiscal year 1991. USDA-SBIR has received a small number of grant applications for new industrial crop projects, but they were not funded.

In addition to the USDA-SBIR program, funding for industrial uses of agricultural commodities is provided by the SBIR programs of other Federal agencies. One of the original projects funded by the National Science Foundation SBIR program in 1977, was a project to study the *Feasibility of Introducing Food Crops Better Adapted to Environmental Stress*. Emphasis was placed on food crops, but some new industrial crops, including many of those discussed in this report, were also evaluated. This study played a role in the establishment of Kenaf International, a private company working with the USDA Office of Critical Materials to commercialize kenaf. NSF-SBIR has funded research on milkweed among other crops, although this crop has not been successfully commercialized (4,26).

College and University Innovation Research (CUIR) Program

This program is being proposed by the National Science Foundation. It would function in a manner similar to the SBIR program, but applications for funding would come from universities, not industry. The intention of the program is to allow university researchers to pursue commercialization of their research results without having to leave their university positions as has happened in many cases. Initial funding requests for fiscal year 1991 are $420,000 (8).

State Programs

Fourteen States (California, Connecticut, Indiana, Louisiana, Maine, Maryland, Michigan, Minnesota, Mississippi, Missouri, Montana, New Jersey, Vermont, and Virginia) have loan guarantee programs that are intended to stimulate business activity. Loan guarantee programs are more attractive than loan programs because they are lower cost and share the risk between the public and private sector. The State programs are generally aimed at manufacturing firms and are open to rural and urban businesses. At least 10 States (Connecticut, Indiana, Kansas, Maine, Massachusetts, Michigan, Minnesota, Montana, New York, and Wisconsin) have venture capital programs although none are aimed specifically at rural businesses. The Minnesota program (Greater Minnesota Corp.) may have the strongest rural component (6, 9).

Other Federal Programs

The Small Business Administration (SBA) makes direct and guaranteed loans to small businesses. It is not aimed at rural businesses, but because of the size of the program, it is a significant financial resource for rural businesses. In addition to the loan programs, SBA also supports small businesses through programs that support small business development corporations (SBDC) and small business investment corporations (SBIC). The SBDC program makes long-term capital available to emerging small businesses. The SBIC program encourages investors to make equity capital available to eligible small businesses (14).

The USDA Farmers Home Administration (FmHA) also operates a business and industrial loan program, which provides loan guarantees aimed at rural businesses. Eligible firms can be of any size and as a result loans made under this program tend to be large (14). Additionally, rural development programs provide funding for firms located in rural areas. None of these programs is geared toward commercializing new crops or uses of traditional crops, but firms involved in these activities may be eligible for these programs.

Summary and Conclusions

The foregoing analysis has several implications for development of policies to encourage technical change. Technical change involves research and development, commercialization, and adoption of new products and processes. Constraints, impediments, and opportunities in all three components must be addressed. This chapter has focused on research and development, and commercialization. The factors involved in the adoption of new technologies will be discussed in chapter 5.

The United States has several policies and programs to encourage research and development. Currently, public- and private-sector funding and research for new industrial crops and uses of traditional crops is limited. If new crops and uses are to be commercialized, adequate resources over a sustained period of time will be needed. A new industrial crops and use research and development policy must recognize the role that institutions and economics will play. It is clear that chemicals derived from agricultural commodities can be used for a broad range of industrial applications, and many are technically promising. Technical feasibility, however, will not be sufficient. Chemicals derived from agricultural commodities must be less expensive than those currently available, or provide a superior product in terms of quality, performance, supply reliability, or environmental benefits. Products and processes that fill specific market needs and provide superior quality and performance, and/or lower costs will be more attractive to industry, and it is in those technologies that industry interest will be highest. Research needs for technology development are generally framed within the context of the chemical, physical, or biological sciences. Attention to institutional structure and economic and social analysis is often lacking. This lack of market and economic analysis is a glaring deficiency and a severe constraint to the intelligent allocation of research funding for new crop and new use development. Research policy should include research for social science research as well as for chemical and biological research.

There has been a recent increase in attention to the problems of commercialization. Several programs, although not specific to new industrial crops and uses of traditional crops, are available to aid technology transfer from Federal laboratories to the private sector. However, these programs tend to treat firms homogenously. Policy must be flexible enough to be able to offer a wide range of assistance options. Research, development, and commercialization efforts face different constraints and proceed in different ways in response to industry structure. Industries characterized by many small, highly innovative firms will have different needs than industries composed of very large firms, or small to medium-size firms lacking research capacity. For example, small, innovative firms may need financial help. Lack of information and inexperience with technology transfer from Federal laboratories may be a more serious constraint for large firms that have large research budgets. Finding additional ways to help industry minimize the search costs for information could prove quite beneficial. A successful policy must be able to address these differing needs.

Chapter 4 References

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Chapter 5

Factors Involved in the Adoption of New Technologies by Industry and Agricultural Producers

Many new technologies involving agricultural commodities will not be final consumer products, rather they will be inputs into the manufacture of other products. The new technologies may be new manufacturing processes (to accommodate a new raw material), or intermediate products that will be used in the production of other products (e.g., plastics are used to manufacture final consumer products). Adoption and incorporation of new materials, processes, and technologies into the manufacturing procedures of firms is a key component to the success of newly developed and commercialized technologies that use agricultural commodities.

Economic factors play a major role in industry adoption of new technologies. Industrial use of a new material or technology may require new equipment, design, manufacturing, and operating changes, and worker training. New materials and technologies are unlikely to be adopted unless they provide cost and/or performance advantages relative to technologies already in use. Many of the economic considerations that influence a firm to allocate resources to the research and development of a new product, will influence the adoption of new technologies by firms (see ch. 4).

The adoption of new agricultural technologies by farmers, in addition to manufacturers, must also be considered, because in some cases, new industrial uses will involve crops not currently grown in the United States. Again, economic considerations will play a key role. This chapter examines factors involved in adoption of new technologies and crops by manufacturers and farmers, as well as programs to assist technology adoption.

Adoption of New Technologies by Industry

Industrial adoption of new technology will depend on industry's interest in, knowledge of, and ability to use effectively the new technology. The cost and effectiveness of the search for information about new technologies will influence the speed of adoption. In general, industries characterized by high labor intensity, rapid growth, and competition within the industry, and industries composed of firms of similar size and profitability are more rapid adopters of new technologies (15).

Firms will consider the profitability, the risk and uncertainty of use, and the cost of any necessary management and production changes when evaluating the possible adoption of a new technology (11). New technologies must be cost competitive with current technologies, or offer clear performance advantages. Sometimes, the price of an intermediate material, even if expensive, represents a small percentage of the total cost of the final product, and thus even large price increases for intermediate materials may not be sufficient to encourage the adoption of a substitute material. Use of a new process or intermediate material may require the purchase of new equipment or new worker skills that require additional training. Product design, operating procedures, and manufacturing processes may be needed to use a new technology. The expense of making these changes is an integral part of the decision to adopt a new technology.

Confidence in the performance characteristics of a new material or process is critical to new technology use in strategic applications where acceptable performance variation is narrowly limited. Intermediate materials containing agriculturally derived rather than petroleum-derived chemicals, for example, may have slightly altered chemical characteristics and behave differently in the same manufacturing procedure. Lack of familiarity with this variation is a significant constraint to use in strategic applications, and new materials and processes may first be adopted by firms for use in non-strategic applications. Confidence for strategic applications may be increased if new intermediate material and process standards are developed. However, testing and standard-setting are often done on a volunteer basis by professional societies who have neither the time or resources to make this a priority, or are undertaken by individual firms and are proprietary (18).

The commercialization of biodegradable plastics demonstrates some of these points. The plastics industry is composed of a few major resin producers and several small and medium-sized companies that make plastic products. A few major producers make biodegradable starch-based masterbatch (primarily firms whose major businesses involve corn or starch) and several small to medium-sized firms make biodegradable products such as grocery and trash bags. However, most of the large resin manufacturers who produce degradable resins, produce photodegradable rather than biodegradable plastics[1] (13). This is because of cost considerations associated with methods of production: photodegradable materials can be made by simply adding photosensitive agents or forming copolymers with photosynthetic groups. The characteristics of the materials do not change substantially, so they can easily be processed with existing equipment. Starch-based materials on the other hand, can cost about 25 percent more to produce than photodegradable materials, in large part because high levels of starch require new equipment and processing procedures (13). This cost differential explains why the first commercially available biodegradable plastic products contained 6 to 7 percent starch; that amount of starch can be incorporated into plastics without significant processing and equipment changes (12). Thus, even firms that adopted the starch-based master batch to produce biodegradable plastic products, did so in a way that did not substantially alter their production methods.

Products using agricultural commodities that can easily and cost-effectively fit into existing production procedures are those that will be adopted first. Products that have clear cost or quality advantages, even if new procedures are needed, may also be adopted relatively quickly. Products or processes for which the advantages are not as obvious, will be more slowly adopted if at all. However, even if a new process or product has clear economic benefits, it may still be adopted slowly because firms that could use these new technologies are either not aware of them, or unsure of the type of equipment or training needed to utilize the new products and processes. For these firms, access to accurate information that is specific to their needs can determine whether or not they adopt a new technology. A good technical assistance program could be invaluable in such cases.

Federal technology policy has, for the most part, focused on the research, development, and commercialization of new technologies; technology adoption is generally not given high priority. Federal programs generally encourage the development of cutting-edge technologies and the establishment of new innovative firms to commercialize these technologies. Only limited attention is paid to upgrading the technology and skill levels in existing firms, particularly those lacking research capacity. The potential users of new agricultural commodity-based technologies in many cases will be firms that already exist; some of which may need assistance in learning about and adopting these new technologies. Technology extension programs may be able to offer this assistance.

Technology Extension and Assistance

Technical extension programs generally consist of an accessible office staffed with engineers or experienced industrial personnel who can provide help in solving problems for manufacturing firms. Effective programs make on-site diagnoses, provide customized client reports, and work one-on-one with firms to implement recommendations made by the service and accepted by the firm's manager. These programs help firms, particularly small manufacturers, choose and manage new technologies and equipment, and provide advice on training requirements. Industrial extension services do not provide funds for capital investment or operating expenses; they give technical, not financial assistance. They can, however, financially help small firms via their diagnoses, which may reveal that the problem is one of management, not funding. They can also direct firms to sources of funds, such as State and Federal loan programs for small businesses, and can support firms in their dealings with banks (17).

The Omnibus Trade and Competitiveness Act of 1988 gave the Bureau of Standards (now the National Institute of Standards and Technology, NIST) new responsibilities for technology transfer to manufacturing. The Act directed NIST to create and support non-profit regional centers for the transfer of manufacturing technology, especially to small and medium-size firms. The tasks of the

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[1] Photodegradable plastics are those that have organometallic or metal compounds added, or that have photosensitive functional groups incorporated within the polymer chains so that the plastics degrade in response to ultra-violet light. An example of a photodegradable plastic product is most degradable six-pack beverage rings. Biodegradable plastics are those that have been modified to disintegrate under biological actions. The most common approach has been to blend the plastic polymer with starch, so that under the appropriate environmental conditions, microorganisms will digest the starch, breaking the plastic into small pieces.

Manufacturing Technology Centers are to transfer technologies developed at NIST to manufacturing companies, make new manufacturing technologies usable to smaller firms, actively provide technical and management information to these firms, demonstrate advanced production technologies, and make short-term loans of advanced manufacturing equipment to firms with fewer than 100 employees. Three such centers currently exist (funded at $4.5 million) and three more are planned. The Centers expect to concentrate more on off-the-shelf, best-practice technologies than on high-technology, cutting-edge systems. The primary service offered will be modernization plans customized to fit the needs of individual firms. The Act also authorized $1.3 million for fiscal year 1990 to expand State technology extension programs (17).

The Small Business Administration, primarily through the Small Business Development Centers located mostly on university campuses, use faculty and students to provide business management and marketing advice, and to advise on particular problems, some of which may be technical. There are 53 such centers nationwide in all but four States, funded by State and Federal Governments and universities (17).

At least 40 States have programs to promote technology, but most of their effort and funding goes for research and development in universities and high-technology startup ventures, not to help existing firms adopt best-practice technology. Only 14 programs in 10 States have technology extension programs whose main purpose is direct consultation with manufacturers on the use of technology. In 1988, States spent approximately $57 million for technology transfer and technology managerial assistance (17). Specialists in rural development recognize the importance of technical assistance, and some studies even suggest that lack of appropriate technical assistance is at least as significant a problem for rural firms as finance availability (2,4,9).

Neither the State extension programs nor the NIST programs are specific for industrial crops or uses of traditional crops. However, for small firms to use new crops in their manufacturing processes, or to develop new products using agricultural commodities, the purchase of new equipment and development of new operating procedures may be required. Technology extension programs may be able to provide some assistance in these areas.

Adoption of New Technologies by Agricultural Producers

In addition to industry adoption of new technologies using agricultural commodities, farmers must grow the commodities to provide the raw materials. The adoption of new industrial crops by farmers will be more problematic than the development of new uses of traditional crops. Farmers have accepted and are growing traditional crops. New crops, however, will be riskier for farmers to grow because they lack experience producing these new crops. Factors that affect farmer adoption of new crops will be significant in terms of the overall success of developing new industrial uses for these crops. Economic factors and agricultural commodity programs will influence the attractiveness of new crops relative to traditional crops. Many technical, economic, and institutional constraints need to be resolved before new crops are ready to be commercially grown.

Technical Considerations

Many of the new industrial crops are in the early stages of development and agronomic research is needed before they can be produced. Some problems yet to be overcome for one or more of the new crops include low germination rates and seedling vigor, asynchronous flowering, seed shattering, self-pollination, low yields, and photoperiodism (5,7). Seed dormancy (lack of germination) and poor seedling vigor not only are undesirable agricultural qualities, but diminish the opportunities for scientists to continue research on that species. Asynchronous flowering (flowering of individual plants at different times) allows a wild plant species to survive periods of adverse weather, but in commercial crops may necessitate multiple harvesting, which greatly increases cost. Seed shattering (the inability of a plant to retain its seed after maturation) is also a useful survival tactic in the wild, but greatly decreases the ability to capture the yield from a commercialized plant. Self-pollinating plants are generally preferred to cross-pollinating plants because of improved control. Photoperiodism is important in determining the length of the growing season and will affect the potential for double cropping and the geographic regions where the crop can be grown. Examples of potential new crops that must overcome one or more of these constraints include meadowfoam (insect pollination), *Cuphea* (seed shattering, seed dormancy), *Vernonia* (photoperiodism), and *Lesquerella* (seed dormancy, seed shattering). Sufficient time and resources devoted to research will likely overcome these problems, but lack of germplasm could slow progress.

New crops will be more readily adopted if they do not require large capital investments or major adjustments in the management style of the farm. New crops that do not require purchase of new machinery or equipment, and which complement traditional crops in terms of planting and harvesting time, are likely to be more attractive than new crops that cannot be so readily incorporated into existing farm procedures. Major changes in the plant's physical structure, such as altering plant height, density and degree of branching, and changing the position and structure of the ovule containing the seeds, may be needed to allow use of farm equipment. Additionally, new crops that can play several on-farm roles and present multiple management options may be more attractive. Oats, for example, are still planted in significant quantities because in addition to providing positive net returns, oats use existing farm equipment, are used in crop rotation schemes, provide good ground cover for erosion control, and can be grown for forage and livestock feed.

Economic Considerations

Farmer decisions involving crop mix are based on many factors, including income-leisure tradeoffs, food and occupational safety, and environmental quality. However, a major driving force is the desire to achieve highest expected net returns for the farm enterprise (21). To be accepted by farmers, a new crop must be competitive with other crops that a farmer can produce with the same resources. Crops compete for the same acreage and production resources; the types and quantities chosen for production will be those for which farm profits are greatest. The expected net returns will be influenced by market conditions and agricultural programs.

Role of Net Returns

Production costs include fixed and variable costs. Fixed costs must be paid regardless of whether production occurs, and in the short run, are not the major determinant of crop mix. Variable costs differ depending on what crop is grown, and play an important role in crop-choice decisions. Variable costs include the costs of labor, machinery and fuel, chemicals, seeds, irrigation, etc. Production costs for the same crops can vary widely among geographic regions, leading to geographical specialization in the production of certain crops (21).

Low production costs and positive net returns are not always sufficient to guarantee widespread adoption of a new crop. The net returns of one crop relative to those of another crop will, in large part, determine the extent of adoption. For example, average variable costs of oats in the Corn Belt are about $50 per acre, with receipts of about $102 per acre, yielding a net return of about $52 per acre. Net returns for corn are approximately $227 per acre (receipts of $363 and costs of $136) and are about $162 per acre for soybeans (receipts of $216 and costs of $54). Oats have lower production costs than corn or soybeans, and are profitable, but in 1987, 6.9 million acres of oats were planted in Illinois, Indiana, and Iowa, whereas 24.4 million acres of corn and 20.9 million acres of soybeans were planted. The most acreage was planted to the crops with the highest net returns (3,19,21).

Risk will play a role in a farmer's perception of net returns. A great deal of uncertainty exists surrounding the production of a new crop. Culturing and harvesting practices, handling procedures, markets etc. are not well-established. This uncertainty increases a farmer's risk, making it likely that farmers will discount the expected price of a new crop. Even if the expected net returns of a new crop are comparable to those of a traditional crop, the farmer may not plant the new crop. Because of the discounting for the added risk, a new crop may need to have higher expected net returns than traditional crops to be attractive to farmers.

Role of Agricultural Commodity Programs

Agricultural commodity programs will also affect the potential adoption of new crops. A loan rate is established for crops covered by commodity programs. At harvest time, farmers enrolled in commodity programs have the option of selling the crop on the market and paying back the loan rate (if the market price is greater than the loan rate), or of accepting the loan rate and forfeiting the crop as payment (if the market price is lower than the loan rate). Some commodities (i.e., corn, wheat, cotton, rice, barley, sorghum, and oats) have target prices in addition to the loan rate. The difference between the target price and the market price or loan rate (whichever is higher) is called the deficiency payment. Deficiency payments are made on a certain percent of the base acres and yields of the eligible commodities. Because some of the eligible commodities are in surplus, receipt of the deficiency payments requires a mandatory set-aside of base acres (Acreage Reduction Program and Paid Land Diversion). No crops can be grown for market on set-aside acres (1).

Acreage Reduction Programs have a large impact on crop-mix decisions. Two examples illustrate this point. In some areas of the Southeast, Delta, and Southern Corn Belt regions, double-cropping of soybeans after harvesting winter wheat is a common practice. If a farmer participates in the wheat program, the farmer can plant soybeans only on that acreage previously planted to wheat. If a large acreage reduction requirement is in effect, the amount of land eligible for double cropping soybeans is significantly reduced (20). In the Corn Belt, the two major crops grown are corn and soybeans. An acreage reduction requirement for corn has a substantial impact on soybean acreage. In the presence of an acreage reduction program, corn acreage changes more in response to a price change than it does under free market conditions. However, in the presence of an acreage reduction program for corn, changes in soybean acreage (in response to a change in the price of soybeans) are lower than would occur under free market conditions. Additionally, changes in soybean acreage in response to a change in the price of corn are higher in the presence of a corn acreage reduction program relative to free market conditions. Thus, the effect of acreage reduction programs on farmer response to the relative prices of crops leads to a different allocation of farm acreage than would occur under free market conditions. Specifically, the presence of corn acreage reduction programs magnifies the impact of corn prices, and diminishes the impact of soybean prices on a farmer's decisions regarding the number of soybean acres to plant (8,21). It is reasonable to assume that new crops competing for acreage with crops that are subject to acreage reduction programs will experience similar impacts. This has significant implications for the adoption of new crops.

Commodity program restrictions that prohibit growing crops other than program crops on base acreage, inhibit crop diversification. However, even if this constraint is relaxed somewhat, acreage of other crops may not increase significantly because of the loss of deficiency payments. Under the Food Security Act of 1985, and the Food Security Improvement Act of 1986, soybeans and sunflowers cannot be planted on underplanted base acreage of commodity program crops without losing those base acres. The Disaster Assistance Act of 1988 relaxes this provision and allows plantings of sunflowers and soybeans on 10 to 25 percent of permitted acreage for major program crops without loss of base acreage, provided that the increased planting does not depress the expected soybean prices below 115 percent of the loan rate for the previous year. Using net returns, and including the deficiency payments received for corn, cotton, spring wheat, and barley, the impact of the program on soybean acres and sunflower acres was estimated. The results indicate that even though base acreage is not lost, the loss of deficiency payments is sufficient to require higher-than-expected soybean prices to encourage farmers to plant soybeans on base acreage instead of corn in the Corn Belt, and instead of cotton in the Delta region. Likewise, it is estimated that there will not be much of an increase in sunflower production relative to spring wheat or barley production in the Plains States. Hence, even if alternative crops are allowed to be planted on base acres of commodity program crops without loss of the base acreage, the expected price of the alternate crop must be high to offset the deficiency payment (21).

As this report was going to press, Congress passed the 1990 Farm Bill. The Bill addressed some of these issues by adopting a Triple Base Option, to begin in 1992. Under this option, base acreage is divided into three categories: acreage reduction program (ARP), program acreage (permitted acres), and flexible acreage. The ARP acres and 15 percent of the base acres are ineligible for deficiency payments. Designated crops may be planted on up to 25 percent of the base (flexible acres).[2]

To demonstrate how the program works, assume that a farmer has a 100-acre corn base and a 10 percent ARP is in effect. Under these conditions, 10 acres (ARP) are idled, leaving 90 acres on which crops can be grown. Any designated crop can be grown on 15 acres but will receive market prices only (i.e., no deficiency payments).[3] The remaining 75 acres (permitted acres) can be planted to corn and are eligible for deficiency payments. An additional option offered to farmers is that 10 of these 75 acres can be planted to designated crops other than corn without a loss of base acres. Thus a total of 25 acres (25 percent of base) could potentially be planted to crops other than corn and still maintain the 100 acre corn base (flexible acres), but only a maximum of 75 acres will be eligible for deficiency payments.

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[2] Designated crops include grains covered by commodity programs, oilseeds, and other crops designated by the Secretary of Agriculture, possibly including many of the industrial crops discussed in this report. Fruits, vegetables, and dry edible beans are excluded.

Additionally, target prices have been nominally frozen at 1990 levels, but changes in the way deficiency payments are calculated may effectively reduce target prices. These changes are expected to increase planting flexibility and to remove some of the institutional constraints to the adoption of new industrial crops. New industrial crops will still need to compete with traditional crops in terms of profitability on the flexible acreage, but profitability will be based more on market prices than on commodity program prices.

Role of Multiple Uses

Multiple uses of primary products and byproducts derived from new crops will improve their commercial prospects. Soybeans illustrate this point. Two major products are derived from soybeans: oil and a high protein meal that remains after oil extraction. Soybean oil is used primarily for edible purposes (70 to 75 percent of the U.S. edible oil use), but also has industrial uses. The meal is used primarily as livestock feed. On average, the price of a pound of soybean oil is about three times the price of a pound of meal. However, the value of the meal accounts for 60 to 65 percent of the value of a bushel of soybeans because soybeans are only 18 percent oil (10). Production of soybeans solely for oil appears unlikely to result in a farm price high enough to make soybeans an attractive crop. Many new crops being developed for the industrial use of one primary product (i.e., the oil from oilseed crops, rubber from guayule, etc.) will likely face a similar situation. Combined food and nonfood uses of the primary product may not result in prices that are favorable for the new crops. Markets for byproducts will need to be developed. Simultaneous development of multiple markets for new crop products is imperative.

Use of Existing Infrastructure

Adoption of new industrial crops will be facilitated if the new crop can readily be accommodated, with minor adjustment, by existing transportation, storage, processing, and marketing infrastructure. Individuals or firms may be unwilling to make large capital investments for a crop that may be low volume (at least initially) and for which the market is not secure. The commercial development of soybeans illustrates many of the concepts discussed in this chapter (see box 5-A).

Agricultural Extension

The largest Federal program to aid in the adoption of new technologies is the Agricultural Extension Service (AES). Funding is approximately $1.2 billion (31 percent Federal) per year. There are offices in nearly every county in all 50 States, with a staff of 9,650 county agents and 4,650 scientific and technical specialists. The AES conducts educational programs to help farmers and agribusiness firms use the results of agricultural research. Historically, it has been successful in helping farmers adopt new technologies, and will continue to play a substantial role in educating farmers about new industrial crops. Recently, the AES has identified as high priority, the development of strategic marketing approaches to market agricultural commodities. This approach is needed to aid development of new industrial crops and uses of traditional crops. It is too early to judge how successful the AES will be in establishing this approach (16).

Policy Implications

Policy to develop a reliable supply of new industrial crops and uses of traditional crops must consider constraints and opportunities in all phases of technical change. In addition to policies that encourage research, development, and commercialization, there must also be policies that address the adoption of new technologies by industry and farmers (see ch. 6).

A strategic approach is needed to develop new industrial crops and uses of traditional crops. Subsector constraints must be identified and linkages established between the producers of the crops, and the manufacturers and consumers who will use the crops (14). A framework to aid in the identification

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[3] These crops may be eligible for nonrecourse and marketing loans.

Box 5-A—Commercialization of Soybeans

Soybeans are frequently cited as an example of the successful commercialization of a new crop. The history of soybean commercialization shows that considerable time may be required for widespread adoption and use of new crops. Soybeans were introduced into the United States in the early 1800s but were grown primarily for hay and had little economic importance for decades. Imported soybeans were not processed in the United States until around 1910; U.S.-produced beans were first processed in 1914, but commercial processing did not begin until 1922. Processing of soybeans occurred in cottonseed mills that had been adapted to accommodate soybeans, and early production was in areas where processing facilities already existed. Thus soybean production and processing adjusted to existing industry structure; new industries were not created to accommodate soybeans. Once soybeans became firmly established as an important crop, new processing and poultry production facilities located in soybean production regions (10).

Prior to World War II, U.S. production of soybeans was insufficient to meet demand, and the United States imported 40 percent of the fats and oils it used. Soybean production increased following World War II in response to several simultaneous events. First, demand for meat products increased, which placed a premium on high-quality livestock feeds; soybean meal was uniquely suited (because of its high protein and lysine content) to fill that demand. Second, tractors continued to replace horses (decreasing the demand for oats) and new synthetic fibers began to replace cotton, resulting in decreased prices for these commodities. Increasing soybean prices coupled with decreasing oats and cotton prices made soybeans relatively more attractive than these crops and acreage was shifted from producing cotton and oats to soybean production. Third, the Federal Government not only supported research to develop and improve soybeans and processing technologies, but offered production supports as well. Programs for feed grains, cotton, and wheat have often allowed soybeans to be substituted without loss of allotted acreage, and at times, grain farmers have been paid to plant soybeans on that acreage. With the exception of 1975, soybeans have been covered by commodity-loan programs every year since 1941. Historically, large amounts of soybeans have often been placed under price supports, but acquisitions by the Commodity Credit Corporation have been relatively small. Soybean producers use the loan program as a financial mechanism to obtain cash, and then redeem the loans prior to maturity to take advantage of higher market prices (10).

By 1950, the United States was planting 15.6 million acres to soybeans. In 1987, about 57.4 million acres were planted. Highest acreage planted was 71.4 million acres in 1979. Between 1967 and 1969 the United States produced 74 percent of the world's soybeans. By 1984 to 1986, that level had dropped to 56 percent. Nations other than the United States responded to favorable soybean prices and their production increased. Other countries also increased their processing and refining capacity, which helps to constrain U.S. exports of oil and meal compared to beans. In the 1980s, the United States exported 42 percent of the beans, 25 percent of the meal, and 15 percent of the oil it produced (10,18).

Soybeans have never been widely used for industrial purposes. In 1960, about 6 percent of the oil produced was used industrially, while today's level is about 2 percent (10). From a farmer's point of view, soybean prices may be low, but from a manufacturing point of view, soybeans are expensive because of their food and feed uses. Also, higher quality, less expensive alternatives are available. Some new crops and uses of traditional crops may also face this situation (6).

of subsector constraints is the Production-Marketing-Consumption (PMC) system developed by the University of Missouri.[4]

The long history and extensive influence of agricultural commodity programs significantly affects the competitiveness of new industrial crops, and possibly new uses of traditional crops. Changes in agricultural commodity programs may help to remove some of the disincentives to new industrial crops.

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[4] Some of the subsectors identified in this framework include the agricultural research and extension system; the production input supply system; systems that affect resource allocation, such as Federal or State programs that affect land and water use; the credit system; and the marketing system, which includes the collection, transportation, storage and processing of the commodity, and the distribution and promotion of the products made from the commodity.

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Chapter 6

Proposed Legislation and Policy Options

During the first half of the 1980s, U.S. agriculture underwent a difficult period of adjustment. The Secretary of Agriculture convened a Challenge Forum in 1984 to explore ways to alleviate these problems. The New Farm and Forest Products Task Force was created as a result of those discussions. The Task Force issued its findings in 1987, and concluded that agriculture must diversify (6).

This study, and continuing problems in the agricultural sector, have lead to interest in using agricultural commodities as industrial raw materials. Congress wants to help rural economies and small farmers to recover from difficult times, and new crops and uses are viewed as a potential mechanism to accomplish these goals. To increase competitiveness, Congress wishes to accelerate cooperation between the public and private sector to commercialize new agricultural technologies. The perceived lack of interest by the U.S. Department of Agriculture (USDA) in developing new industrial crops and uses spawned the introduction of legislation in the 100th and 101st Congresses. Several policy recommendations proposed by the Task Force have been incorporated in the legislation. The House of Representatives bill is titled the Alternative Agricultural Products Act of 1990. The Senate bill is titled the Alternative Agricultural Research and Commercialization Act of 1990. Boxes 6-A and 6-B provide a summary of the main provisions of these bills.

The Task Force reached its conclusion largely on the assumption that "the world now has in place an enormous and steadily increasing capacity to produce basic agricultural commodities in quantities which well exceed demand." It should be noted that this assumption is not universally accepted. In many parts of the world, available arable land is already under cultivation and the potential for increased irrigation is limited. Increases in supply will come from improved productivity. Evidence exists that increases in agricultural productivity are slowing worldwide. In the United States, it is estimated that by the end of this century, barring major technological change, increases in productivity will be lower than increases in demand, which is assumed to increase as a linear extension of past trends (7). It is hoped that advances in biotechnology and information technology will increase productivity, but at the present time it is not clear when, and to what extent, these increases can be expected. Thus, although there are potential benefits to diversification, further discussion of the urgency and extent of diversification needed is reasonable.

Proposed Legislation

Goals

Effective policy must articulate clear and achievable goals, and provide the necessary mechanisms to attain the goals. The purpose of developing new crops and uses of traditional crops is to bring about technical change in agriculture. In support of this goal, proposed legislation seeks to provide increased funding for research, improve cooperation between public- and private-sector research, and help share the financial risk of commercializing new technologies. It is hoped that these new technologies, while benefiting society as a whole, will specifically improve economic conditions in rural communities and agriculture, particularly for small farms.

An immediate question that arises in developing policy to stimulate new crop and use development is whether policy should be restricted to nonfood, nonfeed uses of agricultural commodities, or whether new food crops should also be considered. Proponents of the nonfood, nonfeed approach argue that industrial uses are more likely to have larger, faster growing, and higher priced markets than food uses. They feel that larger benefits can be achieved if scarce funds are concentrated on new industrial crops and uses of traditional crops. Proponents of including new food crops argue that these new crops diversify agricultural production, increase farm income, and can have positive environmental impacts similar to those of industrial crops. Furthermore, new food crops may be easier to market than industrial crops. In addition to the arguments over what plant types should be included, there is the question of whether animal products should also be considered.

Previous legislation to encourage new uses for agricultural commodities has focused on nonfood, nonfeed uses. The goal of the Native Latex Act was specifically to develop a domestic rubber industry. That goal was later broadened with the passage of

Box 6-A—Alternative Agricultural Products Act of 1990: House Proposal

Purpose

- To increase the commercial use of agricultural commodities produced in the United States.
- To mobilize private-sector initiatives to improve the competitiveness of U.S. agricultural producers and processors.
- To foster economic development in rural areas
- To establish markets for new nonfood, nonfeed uses of traditional and new agricultural commodities.
- To encourage cooperative development and marketing efforts among the public and private sectors.
- To direct, where possible, commercialization[1] efforts toward the development of new products from commodities that can be raised by family farmers.

Institutional Structure—Proposes the establishment of a National Institute for Alternative Agricultural Products, an independent entity within the U.S. Department of Agriculture. The Institute will be directed by a 12-member National Alternative Agricultural Products Board, appointed by the Secretary of Agriculture, and comprised of individuals from the private sector. The Board is authorized to appoint an Advisory Council to help review and recommend applications, monitor research progress, monitor operation of the Regional Centers, and provide technical assistance.

The Board is authorized to establish two to five regional centers. Each center must match the funding provided by the Federal Government. Each center is headed by a full-time director, appointed by the Board.

Activities—The Institute can provide financial assistance via grants, loans, interest subsidy payments, and venture capital. It can enter into cooperative agreements. The Director of the Institute is appointed by the Board, and provides for peer review of applications, research and research findings; requires licensing fees, etc. where appropriate; and disseminates information.

Regional Centers encourage interaction among the public and private sector; identify areas where new products and processes can contribute to economic growth; provide technical assistance and business counseling to small businesses to commercialize new uses; identify projects worthy of assistance; make use of existing programs to accelerate commercialization; advise the Institute Director of proposal viability; and coordinate with Small Business Development Centers and the Institute.

Financial Eligibility Criteria

Research and Development Grants—Applications may be made by public and private educational institutions, public and private research institutions, Federal agencies, and individuals. Applications are peer-reviewed.

Commercialization Assistance—Loans, interest subsidies, venture capital, and repayable grants may be made. Applicants must show that the product is scientifically sound, technologically feasible, and marketable. Eligible applicants include universities or educational institutions, non-profit organizations, and businesses.

Selection Criteria

Research and Development Grants—Selected on the basis of the likelihood of creating or improving economically viable commercial products and processes using agricultural commodities. Criteria shall include potential to reduce costs of Federal agricultural assistance programs; unavailability of other adequate funding sources; potential positive impacts on resource conservation, public health and safety, and the environment; and ability to produce the product near the area where the agricultural commodity is grown.

Commercialization Assistance—Priority is given to applications that create jobs in economically distressed rural areas; and that have State, local, or private financial participation.

Funding—At least 85 percent of the authorized funding shall be for Research and Development Grants, and for Commercialization Assistance. Of the Research and Development Grants, at least two-thirds of the funding will be allocated to projects that have substantial funding from their own resources, and that have entered into contractual arrangements with commercial companies that provide at least 20 percent of the total funding for the project. At least 5 percent of the funding is reserved for 1890 institutions. Funds committed by the Institute for any projects shall not exceed 50 percent of the total cost of the project.

Funding is via a revolving fund of unspecified level. Authorization of appropriations are for fiscal year 1991 to fiscal year 1995.

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[1] In both the House and Senate bills, commercialization is defined as activities associated with the development of prototype products or manufacturing plants, the application of technology and techniques to the development of industrial production, and the market development of new industrial uses of new and traditional agricultural and forestry products and processes that will lead to the creation of marketable goods and services.

Box 6-B—Alternative Agricultural Research and Commercialization Act of 1990: Senate Proposal

Purpose

- To authorize plant research in order to develop and produce marketable products other than food, feed, or traditional forest or fiber products.
- To commercialize such new uses in order to create jobs, enhance rural economic development, and diversify markets for agricultural raw materials.
- To encourage cooperative public/private development and marketing efforts and thus accelerate commercialization.
- To direct commercialization efforts toward products from crops that can be raised by family-sized producers.

Institutional Structure—Proposes the creation of the Alternative Agricultural Research and Commercialization Corporation, an independent, nonprofit entity within USDA, and headed by a nine-member board, composed of members from the public and private sectors. It will have four to nine regional centers overseen by an advisory council and located in institutions of higher education, ARS laboratories, State agricultural experiment stations, extension service facilities, and other organizations involved in the development and commercialization of new products.

The Board oversees the Corporation and advises on research projects to be funded. The regional center advisory boards review applications, monitor ongoing projects, and provide technical and business counseling to entities not seeking financial assistance.

USDA's Assistant Secretary for Science and Education has final veto power over the decisions of the board.

Activities—The Corporation may provide grants for research to develop and produce new industrial products. For commercialization projects, the Corporation may provide financial assistance in the form of direct loans; interest subsidy payments to commercial lenders; venture capital investments; repayable grants matched by private, State, or local funds; and umbrella bonding.

Through the regional centers, the Corporation is to encourage interaction among public and private entities in new product development; identify areas where commercialization could foster rural economic growth; provide technical assistance and counsel to small businesses interested in commercialization; identify new farm and forest products and processes worthy of financial assistance; use existing scientific, engineering, technical, and management education programs to accelerate commercialization efforts; review proposals for financial assistance; and coordinate activities with Small Business Development Centers.

Financial Eligibility Criteria

Commercialization Assistance—Applications may be made by a university or other higher education institution, nonprofit organization, cooperative, or small business concern that is capable of legally complying with the terms and conditions of assistance. Applications are filed with the director of the regional center and must document that the proposal is scientifically sound and technologically feasible, and marketable.

Research and Development Grants—No eligibility criteria are specified.

Selection Criteria

Research and Development Grants—Projects selected must show promise to develop new technologies that use or modify existing plants or plant products to provide an economically viable quantity of new industrial products; show potential market demand, reasonable commercialization time frame, and the ability to grow the raw material at a profit; create jobs in economically distressed areas; have State or local government and private financial participation; be likely to reduce Federal commodity program costs; be unlikely to obtain adequate non-Federal funding; be likely to have a positive impact on resource conservation and the environment; and be likely to help family-sized farms and adjacent communities.

Commercialization Assistance—Projects selected must create jobs in economically distressed areas; have State or local government and private financial participation; have good management qualifications; show strong market demand for the potential product; and show potential for repayment to the revolving fund.

Funding—Funding is to be by a revolving fund. Appropriated funds for fiscal years 1990 to 1993 are to be $10 million, $20 million, $30 million, and $50 million respectively, and $75 million per year for fiscal years 1994 to 1999.

the Critical Agricultural Materials Act to develop a domestic capacity to produce critical and essential industrial materials. New legislation also focuses on the development of new industrial crops and uses of traditional crops rather than on food crops.

It is not clear that developing agricultural commodities as an industrial raw material source will have a significant impact on rural economic development. Clearly, developing new crops and uses of traditional crops can be a component of a comprehensive rural policy, but as a policy in itself, it is unlikely to revitalize rural economies. Furthermore, in the absence of additional programs (e.g., teaching new management skills to farmers, and helping them share the additional risks of new technologies), potential benefits from the development of new crops and uses may accrue primarily to large-scale farms rather than to small farms.

Proposed legislation limits private-sector participation to small firms (for research and cooperative agreements) and to firms that will locate manufacturing facilities in rural areas (for commercialization funding). There are many good reasons for limiting assistance to small firms. These firms are often innovative, but due to lack of resources, are unable to pursue long-term, risky projects. Additionally, it is feared that providing funding to large firms simply displaces private funds that would have been invested anyway.

Limiting commercialization funding to firms that will locate in rural communities is an attempt to achieve the goal of revitalizing rural economies. These goals are laudable, but may be inconsistent with the other goals of the proposed legislation. As already discussed, the goal of rural revitalization may not be achievable by this policy. In addition, many firms that are likely to be involved in the commercialization of these new products and processes, are large rather than small firms. The eligibility restrictions in the legislation are such that in the attempt to achieve one goal (that of rural development), serious constraints to achieving other goals (development of new agricultural markets) may be introduced. Potentially, there are products where the two goals will be compatible, but it is likely to be a subset of the total products that could be developed. This raises the question of whether all goals are and should be equal, or whether some should have higher priority than others.

Institutions

In addition to having clear goals, effective policy must be flexible and offer a range of mechanisms to achieve stated goals. Policies to achieve technical change will need to address opportunities and constraints in the research and development, commercialization, and adoption stages. As a means of administering the new policy, legislation proposes the establishment of an independent corporation housed within USDA. However, it is not clear that industrial uses of agricultural commodities are such unique agricultural technologies that their development can only be accomplished with the establishment of a new corporation. Rather, the impetus for an independent institution arises because of perceptions that USDA is not interested in, nor has been responsive to constituent requests for new industrial crop and use research. Critics point to the lack of funding for new industrial use and crop research as evidence that this is not a USDA priority. The issue raised is one of how the USDA establishes its priorities and allocates its resources to meet those priorities.

The OTA report *Agricultural Research and Technology Transfer Policies for the 1990s* finds that the issues of priority-setting, planning, and resource allocation for agricultural research is a general problem within USDA, and not one limited to new crop and new use research (9). The existence of an agricultural research and extension system that is responsive to user needs, sets research priorities and measurable goals, allocates resources in a manner necessary to achieve those goals, and develops a more effective technology-transfer component could eliminate the need to develop entities with narrow authorities. Arguments can be made that the creation of new programs to address individual research issues is merely a band-aid approach that creates a new level of bureaucracy without significantly affecting the fundamental problems within the agricultural research and extension system. A General Accounting Office review of management procedures in USDA indicates that one major reason why USDA has difficulty in managing initiatives that cut across agencies and programs is because historically, as new needs arose, new agencies were created within USDA to handle these needs. These agencies, over time, develop policies consistent with their perceived goals (but not necessarily with USDA goals), and attract constituencies that support each agency's continuance (8). It could be argued that creation of an agricultural corporation to commercialize new crops and uses continues this trend.

Reauthorization of the Office of Critical Materials (OCM) is an alternative to making fundamental changes in the USDA research and extension system or to establishing a new corporation for developing industrial uses for agricultural commodities. The goals of the Critical Materials Act, which established this office, are more modest than those of current legislation. However, OCM is actively involved in the commercialization of new industrial crops; it has cooperative agreements with the private sector and is engaged in projects with industry to demonstrate the commercial feasibility of some of the new crops. Expansion of the mandate of this office to include new uses of traditional crops, and better coordination with the Small Business Innovation Research Programs, could achieve several of the same goals of the current legislation.

Policy Instruments

The new legislation offers several mechanisms to encourage the development of new industrial crops and uses for traditional crops including funding for research and development, in addition to that provided in other categories of the USDA research title. The new legislation strongly emphasizes and funds technology transfer of research from the public sector to the private sector by funding cooperative research agreements.

Proposed legislation does contain some provision for technical assistance, but it is limited. Staff at regional centers, as well as advisory boards are to provide technical and business counseling to firms that are engaged in commercializing new industrial crops and products. They are to coordinate with the Small Business Development Centers (SBDC) and other regional and local agencies or groups involved in development. Some studies have suggested that lack of technical assistance is at least as important a constraint to rural firms as are financial constraints (1,5). Small rural firms most frequently use local bankers, accountants, and lawyers for technical and business counseling, rather than the SBDC, even though there are 53 such centers in all but four States with a budget of nearly $90 million (4,10). Working closely with, and providing educational classes for local bankers, accountants and lawyers may be an effective way for the regional centers to provide some technical assistance. Additionally, the role of the Agricultural Extension Service might be expanded. Historically, the Extension Service has transferred information about new production technologies to farmers. Recently, the Extension Service has begun to develop a strategic marketing orientation to help farmers and agribusiness focus on market potential.

Technical and business counseling provided by the programs described above will be useful, but in many cases may be inadequate. To use new processes, many small firms may need a detailed evaluation of their management and production strategies. Effective State technical assistance programs frequently make site visits and provide customized reports to clients. These evaluations average 5 to 6 days of service at a cost ranging from $1,000 to $20,000 per client (10). This type of technical assistance will not be provided for in the proposed legislation. Given the potential importance of rural technical assistance to help produce new products from agricultural commodities, Congress may need to consider putting more effort into this aspect of commercialization than is currently available in the proposed legislation. One possibility might be to provide block grants to effective State programs.

Proposed legislation provides funding for commercialization. The legislation defines commercialization as activities associated with the development of new products and processes, the application of technology and techniques to the development of new products and processes, and the market development of new products or processes. Funding targeted for the development of new products and processes would be awarded to innovative firms in a manner similar to the SBIR programs. Funding and adequate technical assistance needed to help the majority of firms lacking research capacity to adopt the newly developed processes, is lacking. Proposed legislation is thus similar to most U.S. technology policy in that it only addresses the issues of new technology research, development, and commercialization, and not the problems of industrial technology adoption.

In addition to commercialization funding and technical assistance, there may also be a need for assistance in financing capital investment and operating expenses, particularly in rural areas. Some studies indicate that debt financing markets in rural communities operate efficiently, and that operating capital is available for rural firms (1,5). However, equity markets in rural areas are generally not so well developed as in urban areas. Congress may wish to explore options that generally improve the effectiveness of equity markets in rural areas. Improving the SBIC programs supported by the Small Business Administration and developing secondary financial markets to help rural lending institutions share risk are two possible avenues to explore.

One function of the Alternative Agricultural Research and Commercialization Board, proposed in the legislation, is to disseminate information about commercialization projects. However little funding is provided for this function. Informing industry of potential research and commercialization opportunities is an important component of generating industrial interest in developing new products using agricultural commodities. There is growing participation of industry in Federal laboratory and industry fairs; this could be a potential avenue for informing industry about publicly funded research on new industrial crops and uses of traditional crops. Additionally, the Critical Agricultural Materials Act specifically provided for the establishment of a database regarding new industrial crops and use development at the National Agricultural Library. New legislation does not explicitly provide for this function. Research conducted at non-land grant universities, and that conducted at State Experiment Stations but without Cooperative State Research Service (CSRS) funding may not necessarily be included in USDA databases. Congress may wish to consider provisions for database maintenance.

A strategic approach is needed for the development of industrial products from agricultural commodities. A first priority is an understanding of the market potential for new industrial crops and uses. Appraisal is needed of the structure of the industries that will use the new agricultural commodities and of competing technologies currently used and being developed. It is impossible to identify all contingencies that might occur, and funding generic research can lead to new insights. However, a shotgun approach to new crop and use development is not likely to be effective, particularly if a short development time frame is desired; some research must focused. A priority of new crop and use commercialization should be the development of a marketing and research and development strategy; social-science research will play a fundamental role. Conceivably this approach could be undertaken in the proposed legislation, but social science research is not explicitly discussed. It is the current lack of research in these areas that makes it difficult to evaluate the commercialization potential of industrial uses of agricultural commodities.

Policy Options

Policy options presented are in three categories:

1. commodity programs options;
2. research, development, and commercialization proposals; and
3. additional options that require further study.

Commodity Program Options

Agricultural commodity programs, as they currently exist, provide substantial barriers to the adoption of new crops by farmers. Additionally, these programs skew farmer production decisions so that a few crops are produced in surplus (e.g., corn) while other crops are not produced in quantities sufficient to meet domestic demand (e.g., oats). Agricultural commodity programs have three main components: non-recourse loans, target prices (deficiency payments), and supply-control programs. Simultaneous adjustments in at least two, and possibly all three of these components will be needed to remove barriers to diversification.

Agricultural commodity programs have a major impact on farmer planting decisions. The risk of losing future base acreage if crops other than those enrolled in commodity programs are planted, is a significant impediment to the planting of any crops other than specified commodity program crops. Farmers continue to plant acreage to certain crops even when these crops are in surplus and market signals indicate other crops might be more profitable to grow. Planting disincentives exist not only for new crops, but for many traditional crops as well. Because of surplus production, Acreage Reduction Programs (supply control) are implemented.

OTA proposes four options for commodity programs:

- changes in the commodity base acreage formula to increase planting flexibility, referred to hereafter as "Normal Crop Acreage";

- changes in the commodity base acreage formula to increase planting flexibility, referred to hereafter as "Triple Base Option";
- changes in the target prices, referred to hereafter as "Target Prices"; and
- continuation of commodity programs similar to those contained in the 1985 Food Security Act, referred to hereafter as "Status Quo."

Normal Crop Acreage

Normal crop acreage (NCA) was the system used in 1978 and 1979 for wheat, feed grains, upland cotton, and rice, and was based on the number of farm acres that had been planted to specified crops in 1977. Which crops should be included in normal acreage is subject to debate. Base acreage is established for the whole farm, rather than for individual crops. Within the NCA concept, farmers can allocate acreage to any crop they chose, so long as the total program crops plus set-aside acres do not exceed the NCA. This program allows increased planting flexibility for the farmer, but decreases the ability of the USDA to control supply. Supply control is particularly difficult if target prices for selected commodities are high relative to market prices of other commodities. Farmers will opt to plant the crop with the high target price. Thus, even though they can plant any crop they chose without losing base acreage, they may still choose to produce certain crops in surplus because of the strong price signal sent by the target prices. Passage of this option, without changes in target prices, will not eliminate many of the disincentives to the adoption of new crops (3). Normal crop acreage is the proposal recommended by the administration.

Triple Base Option

The triple base option is also intended to provide planting flexibility. This option divides base acreage into three categories: land taken out of production; land planted for which deficiency payments are made; and land planted for which no deficiency payments are made but where market crops could be grown. The plan provides planting flexibility on the permitted acreage without risk of losing base acreage. Because the planting decisions made for the third base (that which receives no deficiency payments) are based more on market price signals than on target prices, this option presumably would remove some disincentives to planting new crops, assuming that these new crops are permitted under the terms of the commodity program. However, farm groups generally oppose this option because they feel it is motivated not by a desire to provide flexibility, but rather to reduce payments to farmers because of budget constraints. It is also argued that this plan is inequitable because not all farmers can grow more than one crop profitably due to weather and soil constraints (2).

Target Prices

This option would either change the target price itself, or change the acreage and yields of program crops eligible to receive deficiency payments, which would effectively change the target price. Changes in the base acreage formula only, without changes in target prices, may be insufficient to remove barriers to the adoption of new crops, or to reduce commodity surpluses significantly. These outcomes seem to be likelier with the Normal Crop Acreage than with Triple Base Option, because the Triple Base Option effectively reduces target prices by decreasing the acreage eligible for coverage. Reduction in target prices are expected to result in a dollar-for-dollar reduction in farm income. The Triple Base Option would reduce farm income less significantly. Decreasing target prices combined with the Normal Crop Acreage could result in greater crop diversity. Some concern exists that increased planting of non-program crops by farmers participating in commodity programs would negatively affect prices of those crops and hence, the income of farmers who grow non-program crops without participating in the commodity programs.

Status Quo

Maintaining commodity programs similar to those in the 1985 Food Security Act is unlikely to remove disincentives to the production of new crops by farmers.

Research, Development, and Commercialization Proposals

OTA proposes three alternatives for the research and development of new crops and new uses of traditional crops:

- continuation of the current policy including appropriations for the Office of Critical Materials, referred to hereafter as the "Status Quo";
- establishment of institutions outlined in the House and Senate bills referred to hereafter as the "Agricultural Corporation Alternative"; and

- reorganization of the agricultural research and extension system to be more responsive to end-user needs, referred to hereafter as the "National Research and Extension Policy Alternative."

Status Quo

The status quo option calls for maintaining the Office of Critical Materials as the main office to coordinate the research, development, and commercialization of industrial materials from agricultural commodities. New-use research and development will continue to be mainly the responsibility of the ARS. The SBIR programs will play a small role, and States will develop their own programs. Features and likely consequences of the status quo include the following:

1. The Office of Critical Materials and the SBIR programs are small and relatively isolated programs within USDA. The role of the Federal Government in the development of new crops and new uses of traditional crops is likely to remain modest in size. The Office of Critical Materials is mainly involved in the development of new industrial crops, rather than new uses of traditional crops. New uses of traditional crops will remain the responsibility of primarily ARS and CSRS research. New food crops are not part of the program.
2. Continuation of the Office of Critical Materials will not address the underlying problems of priority setting, planning, and resource allocation within USDA.
3. Coordination of USDA programs will be by informal mechanisms rather than an integral part of the program itself; the Office of Critical Materials (OCM) has no authority over, or input into, the policies of other programs within USDA. The OCM does works closely with individual researchers at the Northern Regional Research Center (ARS) and in land-grant universities to develop the new crops they have identified as potential candidates for commercialization. Coordination between OCM and the USDA Small Business Innovation Program, however, is informal.
4. The goals of the Critical Agricultural Material Act are more modest than proposed legislation. The focus is on the development of a domestic capacity to supply industrial materials that the United States uses on a daily basis and that are currently obtained via imports or from petroleum. The emphasis is on supplying a relatively well-defined market rather than on achieving broad social goals, although one could argue that the security gained by having a domestic source of strategic and essential materials is a worthwhile social goal.
5. Financial selection criteria is not limited to small firms only. The broader range of potential participants, compared to proposed legislation, may increase the commercialization prospects for some products.
6. Small business technical assistance and commercialization loans are not part of the program. However, there is a strong technology-transfer component in the form of demonstration programs with industry, and provision of agronomic data about new crops to farmers and extension personnel.
7. Unlike the legislative proposals, the Critical Material Act contains an explicit provision for germplasm collection. Lack of germplasm is a serious constraint for the development of some new crops.
8. There is currently no long-term commitment of funds to the Critical Materials Office. Development of new uses and new crops will require a sustained and adequate commitment of resources.
9. There will be no explicit funding for generic technology-transfer programs for ARS; technology-transfer funding is strictly for industrial uses of new and traditional crops.

Agricultural Corporation Alternative

This alternative involves the passage of a compromise version of the House and Senate bills. Its features and likely consequences include the following:

1. There will be a significant expansion of the Federal role in research, development, and commercialization of new industrial crops and uses of traditional crops.
2. There will be an additional administrative layer added to USDA, but Department problems of priority setting, research planning, and resource allocation will not be addressed. Furthermore, a new administrative component could potentially add to the difficulties already facing USDA in its efforts to coordi-

nate cross-cutting problems across multiple agencies.

3. No explicit provision exists for the development of a strategic plan to develop new crops and uses of traditional crops. The House bill does provide for hearings to establish goals and priorities; it may be possible to incorporate strategic planning within this framework, but it is not guaranteed. Furthermore, no mention is made of social-science research in any of the proposals. This research, though an integral part of developing new products, is currently lacking.
4. Development of regional centers leads to a more decentralized approach to new crop and new use development. Decentralized approaches increase the likelihood of duplication and neglect of important elements. However, regional centers are closer to problem areas and are likely to have more local contacts than centralized offices.
5. Goals of the legislation may be difficult to achieve without additional policy. Agricultural policy and rural policy are not synonymous, and aiming production at small farms will be difficult to achieve.
6. Financial selection criteria may be too restrictive and diminish opportunities for commercialization. It may be difficult for a new crop or new use proposal to satisfy all, or even a majority of the criteria stated in these bills. Flexibility in the interpretation of the criteria will be needed.
7. Venture capital will be provided under the proposed legislation. Equity capital may be limited in rural areas and this provision could be beneficial. However, other approaches such as expanding equity funding to all rural firms, and improvements in rural equity-capital markets might lead to increased rural development impacts.
8. There is no explicit provision of funds for germplasm collection. It is not clear that proposed legislation considered this as research needed for development of new crops and uses of traditional crops.
9. Some duplication of SBIR program activities may exist.
10. There will be no explicit funding for generic technology transfer programs at ARS; funding is strictly for new industrial crops and uses of traditional crops.
11. There will be no funding for new food crops; this potential avenue for diversification is excluded.
12. No explicit consideration exists for database needs. Some projects may automatically be covered by USDA research databases, but others will not. This could potentially increase the difficulty of information dissemination.
13. Technical assistance provided will be small and in many cases, insufficient. Additional consideration needs to be given to this component of new crop and use development and commercialization.
14. No provision is made for adoption of new processes and technology across industry.

National Research and Extension Policy Alternative

This proposal is based on the assumption that no reason exists to treat new crop and new use research and development differently from other agricultural technologies. The impetus to establish a new corporation to promote the research, development, and commercialization of new crops and uses arises from perceptions that USDA has been unresponsive to this type of research. The perceived lack of responsiveness of the USDA to changing needs and priorities is not limited to new crops and uses of traditional crops. Because of the agency's apparent intransigence, a reevaluation of the agricultural research and extension system is warranted. In the OTA study *Agricultural Research and Technology Transfer Policies for the 1990s*, this alternative is explained in detail.

Essential elements of the proposal include a User Advisory Council composed of elected representatives from farmer organizations, agribusiness organizations, public interest organizations, foundations, and government action agencies. The council identifies problems, recommends goals and funding levels, coordinates industry support, and evaluates progress. The council works closely with the Agricultural Science and Education Policy Board (ASEPB), which will be the research and technology-transfer planning center for USDA. The board is headed by the Assistant Secretary for Science and Education, and will include the Assistant Secretary for Economics, the Administrator of each USDA research and technology transfer agency, chairmen of the committees on policy, and representatives from NIH, NSF, non-land grant universities, and 1890 universities. The board, with the active involvement of the User Advisory Council, sets goals, establishes priorities, assigns agency research responsibilities, and evaluates results, among other duties.

Technical panels are created for each major research and technology-transfer priority. These panels work with the board and provide scientific expertise in the planning process. This proposal provides a basis for effective agricultural research and extension planning in a mission-oriented context. User input is an integral component of the proposal. Allocation of funding is to priority programs rather than agencies. Features and likely impacts of this proposal include the following:

1. USDA's fundamental problems with priority setting, planning, resource allocation, and technology transfer will be addressed.
2. New crop and new use research and development may not necessarily be designated a priority area by the User Advisory Council. Proponents argue that because new crops and uses do not have a constituency, they will not receive attention; however, this research has been given attention by the Secretary of Agriculture, and has been designated as priority area by the current User's Advisory Board.
3. Funding will depend on whether new industrial crop and use development is considered essential to the health of agriculture. If so, new crop and new use research will be a priority and a sustained level of funding will occur. However, there is flexibility to reduce or eliminate this funding if priorities change.
4. Because the technical panels help to identify all areas of research that will be necessary to achieve stated goals, a flexible and multidisciplinary systems approach to agricultural research, development, and extension that cuts across USDA agencies, will be established. This approach would allow, for instance, for the collection of germplasm and for social-science research. This approach also allows for the development of some types of information necessary for technical assistance. It would also encourage the development of a marketing strategy and provide for the assessment of likely impacts of the new technology.
5. This proposal is a research and technology-transfer proposal and would not provide funding for commercialization or prototype plant development.
6. Explicit funding for technology transfer programs at ARS is possible but not guaranteed under this proposal. Technology transfer from Federal labs other than USDA might not be included, but representatives from other agencies sit on the Board.
7. Increased funding for new food crops is possible but not guaranteed.
8. The role of the Agricultural Extension Service will be an important part of the program.

Options Requiring Further Study

Following is a list of options which Congress may want to explore further to enhance the potential of new industrial crop and use of traditional crop commercialization.

Financial Options

Rural debt markets seem to be working efficiently, but equity markets are not as well developed in rural areas. Congress might want to engage a study to explore possibilities to improve rural equity markets. This might include development and improvement of secondary financial markets as one possibility. For rural development to occur, a wide diversity of employment opportunities must be made available. Venture capital for more than just plants to produce products using agricultural commodities is needed.

Technical Assistance

Technical assistance, particularly in rural communities is a serious constraint for firms. Technical assistance, as well as improved access to funds for capital investment and operating expenses is needed to enhance the potential of adoption of new technologies and processes by firms. Improved access to training will also be needed. Programs to improve the delivery of technical assistance should be examined. One possibility might be to provide block grants to State programs that are effective at delivering technical assistance to rural firms.

Germplasm Collection

To develop new crops and improve traditional crops, availability of appropriate germplasm will be needed. Germplasm collection, improvement of facilities, and research on new storage and maintenance technologies is needed.

Small Farm Programs

Small farm operators may need to learn new management skills to use new technologies and face difficulties managing the risk associated with new technologies. Programs that aid farmers in these endeavors may help facilitate new technology benefiting small farms.

Macroeconomic Policy

The U.S. Government now has large and growing debts. Numerous studies have demonstrated the adverse impacts this has had on agriculture and rural economies. Finding solutions to the Federal deficit will be important to improving the agricultural sector and rural economies. In addition, tax policy can be used to improve the general economic climate for research, development, and commercialization of new technologies.

Current Legislative Activity

Congress passed a Farm Bill in the fall of 1990, just as this report was going to press. The report, in draft, was made available to the Senate and House Agricultural Committees prior to passage of the Farm Bill. A compromise version of the House and Senate Alternative Agricultural bills was passed as part of Title XVI, the research title of the Farm Bill. The final bill (the Alternative Agricultural Research and Commercialization Act) is similar to the Senate proposal with minor changes. There are provisions for two to six regional centers rather than up to nine as was previously proposed. Additionally an explicit category of funding exists for new animal products. And, eligibility for commercialization funds is no longer restricted to small firms.

Because of incompatible timing of the Farm Bill and Appropriations legislation, funding for the new Alternative Agricultural Research and Commercialization Center was not provided. Instead, the Critical Agricultural Materials Act was reauthorized through FY 1995 and the 1991 funding for the Office of Critical Materials is $800,000. Other funding provided for new crops and uses of traditional crops include $668,000 for guayule research and $500,000 for *Crambe* and rapeseed research. Research funds for kenaf ($1,106,000), meadowfoam, jojoba, milkweed, soybean oil inks, and plastics from cornstarch are also provided for in the ARS budget and special grants. Additionally, there is a grant program for research on the production and marketing of ethanol and industrial hydrocarbons from agricultural commodities and forest products authorized at $20,000,000 per year for fiscal years 1991 through 1995. It is likely that Congress will take up the issue of funding the new programs authorized in the Farm Bill in 1991.

Changes were also made in the agricultural commodity programs. Congress passed a Triple Base Option plan, to begin in 1992. Under the plan, the base acreage for program crops (wheat, corn, grain sorghum, oats, barley, upland cotton, or rice) is established. Acreage Reduction Programs (ARP) will remove a percentage of that acreage from production. Program crops or other designated crops (i.e., oilseeds and industrial or experimental crops designated by the Secretary of Agriculture), can be planted on 15 percent of the base acreage, but are not eligible for commodity support payments. An additional 10 percent of the base acreage can be planted to designated crops without loss of program base. This new flexibility provision, and removal of acreage that is eligible for support payments will help to remove some of the disincentives to the planting of new industrial crops. Additionally, target prices were nominally frozen at 1990 levels, but changes in the method of calculating deficiency payments may effectively lower target price levels.

In addition, Congress created a new Agricultural Science and Technology Review Board consisting of 11 representatives from ARS, CSRS, Extension Service, Land Grant Universities, private foundations and firms involved in agricultural research, technology transfer, or education. The purpose of the Board is to provide a technology assessment of current and emerging public and private agricultural research and technology-transfer initiatives, and determine their potential to foster a variety of environmental, social, economic, and scientific goals. The report of the Board is to include an assessment of research activities conducted, and recommendations on how such research could best be directed to achieve the desired goals. Establishment of this Board is an attempt to address some of the fundamental problems existing in the USDA research and extension system.

Conclusion

Using agricultural commodities as industrial raw materials will not provide a quick and painless fix for the problems of agriculture and rural economies.

They can provide future flexibility to respond to changing needs and economic environments, but many technical, economic, and policy constraints must be overcome. Many of the new industrial crops and uses of traditional crops are still in relatively early stages of development. Several years of research and development will be necessary before their commercialization will be feasible. The lack of marketing strategies and research to assess the impacts of new technologies complicates decisions on research priorities and appropriate policies and institutions needed to achieve success. Potential impacts on income reallocation and the environment, as well as regional effects need further study before large-scale funding for commercialization is required. Successful commercialization will require not just funding assistance, but a systemic policy that articulates clear and achievable goals and provides the instruments needed to reach those goals.

An encompassing research and development strategy is needed and must be designed to meet market needs; hence a strategic, multidisciplinary, multiregional approach should be taken with both public and private sector involvement. Changes in agricultural commodity programs, in addition to those already made, may still be needed to remove disincentives to the adoption of many new crops. Because of research information still needed, and the time still required to develop many of the new crops and products, a two-step approach to commercialization might be useful. The European community is taking this approach by first establishing a precommercialization program to determine feasibility, and then following up with a later program to encourage commercialization. The U.S. Small Business Innovation Research Program also takes a multistage approach to the commercialization of new technologies. In the United States, initial primary emphasis could be given to the basic, applied and precommercialization research needed to develop new crops and uses. A high priority should be an early technology assessment of products and processes to analyze potential markets, socioeconomic and environmental impacts, technical constraints, and areas of research needed to address these issues fully. The establishment of the USDA Science and Technology Review Board should improve the prospects for this type of assessment. The technology assessment would lay the groundwork for development, and provide the information needed to make intelligent decisions about commercialization priorities, possible impacts of new technologies, and further research or policy actions needed.

Interdisciplinary, and in appropriate cases, multiregional research should be given the highest funding priority. This could include: chemical, physical, and biological research needed to improve production yields and chemical conversion efficiencies, and to establish quality control and performance standards; agronomic research to improve suitability for agricultural production; germplasm collection and maintenance research; and social science and environmental research. Technology transfer issues should also be addressed. These issues include funding for cooperative agreements, database management, and Federal laboratory-industrial conferences.

Once information is available to identify market potential and technical, economic, and institutional constraints, the second step to commercialization can be made. A strategic plan can be developed to commercialize the most promising technologies. Financial aid for commercialization and the role of regulations may need to be considered. Industrial adoption and diffusion of new processes may require additional technical assistance and technical extension programs. For new industrial crops and uses, additional changes may be needed in agricultural commodity programs.

Because many new industrial crops and uses of traditional crops are still in the early stages of development, there is time for a thorough analysis of the actual potential of these new products, the constraints to commercialization, and the potential impacts of development. This information, once it is available, will permit the design of appropriate policy and institutions needed to achieve the benefits that may exist.

Chapter 6 References

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Appendix A
Selected New Industrial Crops

Bladderpod

Scientific name: *Lesquerella* species

Major compounds produced: The seeds contain 11 to 39 percent oil of which 50 to 74 percent are fatty acids containing hydroxy groups. The predominant hydroxy fatty acids produced are lesquerolic acid, densipolic acid, and auricolic acid. Individual species of *Lesquerella* tend to specialize in the production of one of the three hydroxy fatty acids to the exclusion of the other two. After oil extraction, a high-protein meal that is relatively high in lysine remains.

Replacement: Imported castor oil (mainly the hydroxy fatty acid ricinoleic acid).

Major uses: Hydroxy fatty acids are used primarily in plastics. The oil from *Lesquerella* can be used to produce a plastic that is tougher than those currently available.

Agronomic characteristics: *Lesquerella*, a member of the Cruciferae family, contains about 70 species and is native to dry areas from Oklahoma to Mexico. It produces thick stands in the wild, is relatively tolerant of cold, and can survive with annual rainfall of 10 to 16 inches (25 to 40 cm). Observed yields of species in the wild have ranged from about 979 lb/acre of seed (1,100 kg/ha) to 2,000 lb/acre.

Technical considerations: The chemical structures of the hydroxy fatty acids produced by *Lesquerella* are similar, but not identical, to that of ricinoleic acid (castor oil). Extensive testing and evaluative studies will need to be conducted to determine if these hydroxy acids can substitute for ricinoleic acid. About 20 species of *Lesquerella* have been field tested in Arizona. *L.* fendleri appears to be the most promising for domestication. It displays significant genetic variation leading to easier selection for agronomic characteristics. However, *L.* fendleri suffers from seed dormancy and seed shattering, which increases research and commercialization difficulties. The meal contains glucosinolates.

Economic considerations: Brazil and India are the major producers of castor beans. Between 1983 to 1986, production in those two countries has ranged from 524,000 metric tons (MT) to 886,000 MT, with 1986 output of 586,000 MT. This erratic production has contributed to highly variable prices for castor oil. U.S. imports of castor oil have increased somewhat, but because the United States is a major purchaser, too large an increase in imports would significantly raise the price. Castor oil is classified as a strategic oil and is stockpiled.

Social considerations: It is possible to grow castor beans in the United States but because of the high toxicity and allergic reactions experienced by field workers, it is not done. No other plant tested has been found to produce high levels of ricinoleic acid. *Lesquerella* is adapted to dry climates and requires fertilizer levels equivalent to other alternatives that could be grown in the same area.

Extent of research conducted: *Lesquerella* was identified early as a high producer of hydroxy fatty acids in the Northern Regional Research Center (NRRC) screening of potential industrial plants, but only recently has research interest been shown. The Agricultural Research Service of the U.S. Department of Agriculture and the United States Water Conservation Laboratory in Phoenix, Arizona, have collected germplasm. Plant breeding to improve yields, and water management studies are being conducted at Phoenix. Much of the research to date has been evaluating the seeds for oil content and concentration. Some utilization research is being conducted at the NRRC in Peoria (substituting *Lesquerella* for ricinoleic acid). The Cooperative State Research Service (CSRS) through the Office of Critical Materials is spending $20,000 on crushing and assessment work at the NRRC.

SOURCES: 36,43,44,46

Buffalo Gourd

Scientific name: *Cucurbita* foetidissima

Major compounds produced: Seeds of wild species are 21 to 43 percent oil by weight with a mean of 33 percent. Some hybrids that have been developed have seeds that are 38 to 41 percent oil with a mean of 39 percent. Among the hybrids analyzed, the fatty acid distribution was palmitic-7.8 percent, stearic-3.6 percent, oleic-27.1 percent, and linoleic-61.5 percent. Among wild species, there is an inverse relationship between linoleic and oleic acid concentration. The meal that remains after oil extraction is about 30 percent protein by weight. It is relatively low in lysine. The roots contain high levels of starch. By dry weight, first-year roots are 47 to 64 percent starch, and second-year roots are 50 to 65 percent starch.

Replacement: Epoxy fatty acids derived from sunflower oil, soybean oil, and petroleum. The root could be used as a feedstock for ethanol production.

Major uses: The fatty acid distribution of the oil is very similar to that of sunflowers. Buffalo gourd oil could be used for the same industrial uses as sunflower and soybean oil; it could be converted to epoxy fatty acids and used in the pl[illegible]s and coatings industry. The meal could be used as livestock feed. The starch could be used as a feedstock for ethanol production.

Agronomic characteristics: Buffalo gourd is a wild member of the squash and pumpkin family. It is native to the arid and semiarid regions of North America and could be grown in the Ogallala aquifer region. It can survive in regions with as little as 6 inches (150 mm) of rain, but probably will require at least 10 inches (250 mm) of water to achieve economical yield levels. It is relatively intolerant of cold temperatures, and cannot tolerate poorly drained soils. Buffalo gourd can be grown either as an annual or a perennial. Utilizing a perennial cultural system optimizes seed yield (oil production) and limits root (starch) yield. The annual mode of production optimizes root yield. Conservative estimates of seed yield are 1,780 lb/acre (2,000 kg/ha). Some experimental plots using hybrids have averaged 2,760 lb/acre (3,000 kg/ha) with one plot producing 2,914 lb/acre (3,274 kg/ha). Starch yields of 6,061 lb/acre (6,810 kg/ha) have been achieved experimentally.

Technical considerations: Increased yields, efficient harvesting techniques, and improved disease resistance are needed.

Economic considerations: Fatty acids derived from the oil of buffalo gourd, like sunflowers and soybeans, must be chemically converted to epoxy fatty acids. It is the cost of this conversion, more than the cost of the raw oil, which limits the use of natural oils to provide epoxy fatty acids. Buffalo gourd may not have an advantage over sunflower or soybean oil for these uses. As a feedstock for ethanol production, buffalo gourd might have potential. It takes approximately 1.8 to 1.9 kilograms of starch to produce one liter of ethanol. Therefore, it is possible to produce approximately 404 gal/acre (3780 l/ha) of ethanol from the roots. It is estimated that buffalo gourd priced at about $25 per ton would be competitive with grains for ethanol production.

Social considerations: Buffalo gourd is adapted to arid climates and irrigation requirements are lower than those of many other crops which could be grown in those regions. It provides extensive ground cover and, particularly if grown as a perennial, could reduce erosion on susceptible soils. Buffalo gourd is a plant that might have more uses in developing countries than in the United States. The starchy root can be dried and used as cooking fuel rather than wood, and the oil from the seed is edible.

Extent of research conducted: Buffalo gourd research is conducted at the University of Arizona.

SOURCES: 10,13,15,43,44

Chinese Tallow

Scientific name: *Sapium* sebiferum

Major compounds produced: The seeds are 25 to 30 percent hard vegetable tallow and 15 to 20 percent oil. The tallow is a single triglyceride containing palmitic and oleic acids. The oil contains oleic, linoleic, and linolenic acids.

Replacement: Imported cocoa butter

Major uses: Potentially the tallow could be used as a substitute for cocoa butter and the oil could possibly be used as a drying oil for paints and varnishes.

Agronomic characteristics: The Chinese tallow tree is a member of the Euphorbiaceae family and is native to subtropical China. It currently is grown in the South Atlantic and Gulf Coastal Plains and in some areas of southern California as an ornamental. It is best adapted to semitropical climates. Chinese tallow is tolerant of salinity and can be grown on poorly draining soils. Seed production can begin in the third season of growth and yields up to 10,000 lb/acre can be achieved. The seeds ripen in the fall. The tree can live 50 years.

Technical considerations: Need to increase yields, and utilization research.

Economic considerations: The United States imports 70,000 to 80,000 metric tons of cocoa butter each year, valued at about $348 million. One study estimates a possible net return of $3,200 per hectare per year after 5 years.

Social considerations: Chinese tallow will grow on more marginal lands. Since it is a perennial and requires a long time to yield, it may be more suitable to plantation type of growth.

Extent of research conducted: The Small Business Innovation Research program of the National Science Foundation (flowering, biology, ecology, and genetics), the NRRC (oil characterization), and the Short Rotation Woody Crops Program of the Department of Energy (agronomic) have provided research funding.

SOURCES: 29,39,46

Coyote Bush/Desert Broom

Scientific name: *Baccharis* pilularis (coyote bush), *Baccharis* sarothroides (desert broom).

Major compounds produced: Approximately 10 percent of the dry weight of the plant are resins.

Replacement: Wood rosins

Major uses: Could be used in rubbers and chemicals.

Agronomic characteristics: *Baccharis* is a member of the Compositae family. The genus consists of over 300 species of dioecious, sometimes evergreen shrubs, which are native to North and South America. The genus contains arid-adapted species. *Baccharis* pilularis is native to Baja and southern California, where it is often grown as a landscape plant. Attempts to grow it in Tucson, Arizona, were unsuccessful due apparently to a sensitivity to high temperatures and low humidity in combination with overwatering. *Baccharis* sarothroides is better adapted to the drought, heat, cold, and high salinity of its native Sonoran Desert environment.

Technical considerations: Hybrids of *B*. pilularis and *B*. sarothroides have been achieved. All of the hybrid plants obtained displayed pistillate (female) sexual expression. Excess production of pappus on female plants is a nuisance and a fire hazard, and staminate (male) sexual expression is preferred. Research is needed in this area as well as in the production yields of resins.

Economic considerations: Currently, annual U.S. production of rosin, is about 600 million pounds. High quality wood rosin comes from aged pine stumps, but this supply is diminishing. Tapping of live trees to obtain gum rosins is very labor intensive and expensive, and production from this source is also declining. Currently, U.S. production of rosins comes mainly from recovery of tall oils, byproducts obtained from the manufacture of chemical wood pulp. It is estimated that the United States consumption of resin will be 781 million pounds (3[illegible]5 million kilograms) by the year 1990.

Social considerations: *Baccharis* tolerates arid conditions and requires less irrigation than crops that are currently grown in the Southwest.

Extent of research conducted: In 1975, at the University of Arizona, Tucson, *B*. pilularis and *B*. sarothroides were crossed to achieve an interspecific hybrid, which combined the arid land adaptability of *B*. sarothroides with the compact growth of *B*. pilularis. The hybrid was released by the University of Arizona Experiment Station as an ornamental shrub, under the name of Centennial.

SOURCES: 43

Crambe

Scientific name: *Crambe* abyssinica

Major compounds produced: The seeds are 30 to 45 percent oil, 50 to 60 percent of which is erucic acid, a C_{22} monounsaturated fatty acid. After oil extraction, there remains a meal that is about 28 percent protein.

Replacement: Imported high erucic acid rapeseed.

Major uses: Currently, erucic acid and its derivatives erucamide and behenylamine are used in plastics, foam suppressants, and lubricants. Potentially, the oil could be hydrogenated to yield a hard wax that could be used in cosmetics and candles. Oxidative ozonolysis of erucic acid yields brassylic acid and pelargonic acid. Brassylic acid can be transformed into a liquid wax for use in high-pressure lubricants and industrial paints and, to make industrial nylons, such as nylon 1313, for use in electrical insulation, automobile parts, and other high-temperature applications. Pelargonic acid can be used in lacquers and plastics. The protein meal could be used as a livestock feed or as an adhesive for plywood.

Agronomic characteristics: *Crambe* is a member of the Cruciferae family and is native to the Mediterranean region. It is planted in the spring, has a short growing season of 90 to 100 days, and can be grown in all of the 48 lower states of the United States. *Crambe* tolerates dry conditions well but will not tolerate heavy, wet soils. Seed yields in experimental plots have ranged between 1,000 to 2,500 lb/acre, with the Meyer cultivar yielding 2,163 lb/acre. Commercial yields are expected to be about 1,500 lb/acre. Delayed harvest can lead to seed shattering.

Technical considerations: There appears to be no technical barriers to the direct substitution of *Crambe* oil for high erucic acid rapeseed oil. *Crambe* is susceptible to the fungus *Alternaria* brassicicola and turnip mosaic virus, and broadleaf weeds can be a problem. Currently there are no herbicides approved for use on *Crambe*; approval for Treflan is being sought. The seeds are very small and very lightweight, placing a premium on proper seed handling. Leakproof equipment may be needed. The seeds are covered by a hull which must be removed prior to processing. Dehulling equipment similar to that used for sunflower seeds is needed. A lack of cold-tolerant varieties diminishes the opportunity to plant *Crambe* as a winter crop in the Southeast. *Crambe* seeds can contain up to 8 percent glucosinolates, sulfur-containing compounds attached to glucose molecules, which have been linked to thyroid disturbances, liver damage, throat abscesses, appetite depression, tongue swelling, and abortion. Meal with high levels of glucosinolates can generally be fed to beef cattle (ruminants), but not to swine and poultry. The U.S. Food and Drug Administration has approved crambe meal (obtained by solvent extraction) use in beef finishing ratios at concentrations of less than 4.2 percent of the total weight of the ration.

Economic considerations: World production of rapeseed oil has increased nearly 35 percent since 1984, although much of that increase is due to canola (edible) quality oil, and not industrial-quality oil. The current U.S. market for high erucic acid oil is approximately 40 million pounds per year. Most of this oil is used to produce erucamide, used as an antislip agent in plastics. An estimated 65,000 to 85,000 acres of *Crambe* is needed to supply this market. Development of a market for industrial nylons made from brassylic acid is estimated to require planting of nearly 300,000 acres.

The estimated production costs per acre, in the Midwest (including land, but excluding transportation costs beyond the farm gate and farm management and risk charges), are $147. *Crambe*/winter rapeseed will compete with winter wheat in the Plains Region. Net earnings of wheat, deficiency payments included, are about $200 per acre. Estimated processing costs for rapeseed oil range between $0.16 and $0.31 per gallon of oil depending on seed volume and oil content, processing plant size, extraction method used, and whether the plant was newly constructed or retrofitted to process rapeseed. Because *Crambe* oil content is less than rapeseed, and the seeds must be dehulled before processing, it is expected that processing costs for *Crambe* will be slightly higher than for rapeseed.

Social considerations: *Crambe* will grow in drier areas than rapeseed and may therefore be more suitable for growth in the Plains Region of the United States. Fertilizer needs are comparable to wheat.

Extent of research conducted: Both *Crambe* and winter rapeseed are crops that the Office of Critical Materials (OCM) is actively trying to commercialize. Congress has appropriated $325,000 for fiscal year 1989 to be used for this purpose. Eight States (Missouri, Kansas, New Mexico, Idaho, Iowa, Nebraska, North Dakota, and Illinois) have formed a consortium in cooperation with the OCM to perform research necessary to lead to commercialization. Funding by these States is estimated to be $2 for every $1 of Federal support.

SOURCES: 15,20,35,36,42,46,49,51,53

Cuphea

Scientific name: *Cuphea* species

Major compounds produced: The seeds are from 25 to as much as 40 percent oil. Some species have oil that contains up to 80 percent lauric acid, a C_{12} saturated fatty acid. Other species contain high levels of C_{10} fatty acids such as capric acid. The meal is high protein.

Replacement: Imported coconut oil (lauric acid, capric acid) and imported palm kernel oil (lauric acid).

Major uses: Currently, palm oil and coconut oil are used both as edible oils and for industrial purposes, primarily in soaps and detergents (as surfactants) and in lubricants.

Agronomic characteristics: The *Cuphea* genus is a member of the Lythraceae family and consists of approximately 250 species native to Mexico and Central and South America. One species, *Cuphea* viscosissima, is native to the United States. Several species are adapted to temperate climates. Experimental plots have yielded 250 to 2,000 lb/acre of seed (280 to 2,240 kg/ha). There are both insect and self-pollinated species.

Technical considerations: The major problems are seed shattering and seed dormancy. Seed yield per se does not appear to be a significant problem, but because of the inability to retain the seeds, harvesting is difficult and yields diminished. Hundreds of populations in several species of *Cuphea* have been sampled, but so far none have demonstrated genetic variability for seed retention. Chemical mutagenesis of seeds to induce genetic variation for seed shattering has been attempted. The results have been disappointing thus far. Seed dormancy in some species has made it difficult to grow populations large enough to continue further evaluations. Species that are insect pollinated have long floral tubes, which preclude access by honeybees to the nectar. Suitable insect pollinators have not been found, causing the discontinuation of research on most of the insect-pollinated species of *Cuphea*. *Cuphea* oil is colored, but this appears to be a minor problem that can be alleviated during processing, if required. It is not known whether the meal contains any antinutritional elements that would prevent its use as a livestock feed. Because *Cuphea* is projected as a domestic source of lauric acid (a very well-established market), extensive utilization research may not be necessary. If the problem of seed shattering cannot be overcome, it is unlikely that *Cuphea* could be commercialized.

Economic considerations: Coconut oil is the major source of lauric acid, but over time, it has been losing market share due to erratic supplies caused by adverse weather conditions and declining productivity of aging coconut plantations in the Philippines. Some new, higher yielding varieties of coconut palms have been developed and are beginning to be planted. It is expected that when these trees mature, coconut oil production will increase. An alternative source of lauric acid is palm kernel oil from Malaysia and Indonesia. Production of both palm oil and palm kernel oil is increasing and potentially could increase significantly more, largely due to increased planting of new varieties of the African palm, which produce high yields of oil, can be grown in marginal lands, and are highly resistant to pests and diseases. It is expected that supplies of palm oil and palm kernel oil will increase substantially when these new varieties mature. The increased production of palm kernel oil coupled with coconut oil is expected to double the supply of lauric acid oils by 1995.

Currently the United States uses about 650 million pounds of tropical (palm, palm kernel, and coconut) oils for food uses (about 5 percent of the U.S. edible oil market). This level of use is about 35 to 40 percent of the total U.S. imports of tropical oils; the remaining imports are for industrial uses. Europe consumes higher levels of tropical oils for food uses than does the United States; increased consumer concern over saturated fats in Europe could potentially decrease European demand. Industrial uses will need to increase significantly to prevent a worldwide glut of lauric acid oils, if supply of palm kernel and coconut oil continues to increase, while the demand for edible uses of these tropical oils decreases.

Oversupply would result in depressed prices for these oils and for potential domestic substitutes such as *Cuphea*. Higher lauric acid yields for *Cuphea* (80 percent) than for coconut oil (40 to 45 percent) may result in a premium for *Cuphea* oil. However, higher transportation and processing costs might offset some of this premium if *Cuphea* is grown in the Northwest. An alternative option for commercialization of *Cuphea* might be to be to develop the species that are high in capric acid instead of those high in lauric acid. Coconut oil contains only 3 to 7 percent capric acid. Although the market for capric acid is smaller than for lauric acid, capric acids fetch higher prices. Thus, varieties higher in capric acid might be more attractive.

Social considerations: *Cuphea* is intended to be an import substitute for tropical oils (coconut and palm kernel oil). These crops are major exports of Indonesia, Malaysia, and the Philippines, developing countries that are of some strategic importance to the United States. The possible impact that loss of these markets might have on the economic stability of these countries is not well-understood.

Extent of research conducted: Early research on *Cuphea* was conducted at the University of Gottingen in Germany. Beginning in 1983, breeding, genetics, and agronomy research was undertaken in the United States. Initial germplasm collections (267 accessions) were made at the USDA/ARS Water Conservation Lab in Phoenix, Arizona. Currently, the germplasm program has been moved to the ARS Laboratory in Ames, Iowa, and has been expanded to include accessions from 50 to 60 *Cuphea* species. A germplasm collection expedition to South America is being planned. In addition to germplasm collection, researchers at Ames, in conjunction with Iowa State University, are attempting to improve the nutritional content of *Cuphea* seeds. There may be some potential to use these seeds as food supplements for infants and the elderly. Researchers at Oregon State University are attempting to develop cultural management practices, prevent seed shattering, and increase the lauric acid content of the oil. Some financial support for *Cuphea* research at Oregon State University is being provided by the Glycerine and Oleochemical Division of the Soap and Detergent Association. The USDA is contributing approximately $100,000 to the project. Some research is conducted at the ARS Laboratory at Tifton, Georgia, to improve agricultural and management practices, and some work is being conducted at ARS Laboratory in Phoenix, Arizona, to develop hybrids. It is estimated that there are approximately four scientist-years total being devoted to *Cuphea* research. Research hours are being allocated among three USDA/ARS positions (one each at Ames, Iowa; Phoenix, Arizona; and Tifton, Georgia) and three research positions at Oregon State University.

SOURCES: 3,12,21,22,34,36,38,44

Guar

Scientific name: *Cyanopsis* tetragonobla

Major compounds produced: The seeds produce a gum. The meal is 35 to 50 percent protein, which contains toxins and is low in lysine.

Replacement: Imported guar

Major uses: Currently used as a strengthening agent in paper, and as a stabilizer in cosmetics, ice cream, salad dressings and oil-drilling muds.

Agronomic characteristics: Guar is a leguminous herb that grows well in semiarid regions, and can be grown in areas of the Southwestern U.S. It tolerates alkaline and saline conditions, and when it receives sufficient rain (15.7 to 35.4 in or 40 to 90 cm) yields of 625 to 805 lb/acre (700 to 900 kg/ha) seed can be obtained. Guar does not tolerate cold. The growing season ranges from 105 to 150 days. The plant itself could be used for forage.

Technical considerations: A major difficulty with guar is its susceptibility to a variety of pests and diseases including the fungus *Alternaria*, the bacteria *Xanthomonas*, and root knot nematodes. There is also a need to improve yields.

Economic considerations: U.S. imports of guar seeds have been decreasing. This decrease may be in part because production of guar is already occurring in the United States and production needs of the country may be close to being met. There may not be a need for expansion of guar production, unless export markets or new uses can be developed. (See table D-5 in app. D for U.S. imports of guar.)

Social considerations: Guar is a legume and has nitrogen-fixing qualities.

Extent of research conducted: Not extensive.

SOURCES: 43

Guayule

Scientific name: *Parthenium* argentatum

Major compounds produced: Guayule produces a high-molecular-weight rubber and resins that are extracted from the whole plant.

Replacement: Imported *Hevea* rubber and synthetic rubber

Major uses: High-molecular-weight rubber is particularly valuable in uses which require elasticity, resilience, tackiness, and low heat buildup such as in tires; resins can be used in the chemical industry; extraction residues could potentially be used as livestock feed.

Agronomic characteristics: The genus *Parthenium* includes 17 species, all native to North or South America. Both annuals and perennials are known. Guayule is the most studied species. It is native to the Chihuahuan desert region of the Southwestern United States and

Northern Mexico and produces a high-quality rubber similar to *Hevea*. In wild stands, rubber percentages have ranged between 3.6 and 22.8 percent of the dry weight, and resin yields have ranged between 2.5 and 9.8 percent by dry weight of plant tissue.

Technical considerations: The major difficulty with guayule is the yield of rubber. Rubber accumulation seems to be a factor of geoclimatic conditions, with water and temperature stress stimulating rubber production. Recently researchers have found the enzyme (rubber polymerase) responsible for synthesizing rubber. This enzyme can be stimulated to produce higher levels by spraying certain chemicals on its leaves, so some of the yield problems might be overcome.

Guayule has been crossed with other species of *Parthenium*, most notably with *P.* fruticosum, to obtain a hybrid. The hybrid contained a lower percentage of rubber than guayule, but the biomass of the hybrid was higher than that of guayule, indicating that total rubber production of the hybrid might be greater than for guayule. In addition, high-molecular-weight rubber (high-quality natural rubber) dominates low-molecular-weight rubber, indicating that the hybrid can produce high-quality natural rubber. Successive generations of crosses, however, displayed decreasing seed germination percentage. Improving seed germination and direct seeding procedures are needed.

Guayule differs from both *Hevea* and other latex-producing plants in that the rubber is contained in single thin-walled cells located on the stems and branches of the shrub. This results in the need for a physical or chemical separation of the rubber from other components in the harvested shrub. Excessive handling results in decreased rubber quality. Improvements are needed in harvesting technology. In addition to problems of yield, large-scale testing of the high-molecular-weight rubber in tires is needed, and uses for coproducts, low-molecular-weight rubber, and other chemical components need to be developed.

Economic considerations: Guayule is intended to replace natural rubber imports from Asia, primarily from Malaysia and Indonesia. From 1983 to 1987, U.S. imports of rubber have averaged 777,000 metric ton per year, and price per pound was about $0.39. It is estimated that for guayule to be competitive with natural rubber, prices for rubber must double, or guayule yields must increase to about 1,200 pounds of rubber per acre. Markets for byproducts also must be found, and production and processing costs must be lowered by at least one-third their present levels. These changes are expected to result in a positive cash flow for farmers and to make guayule competitive with natural rubber, but they may not necessarily make guayule competitive with other crops that could be grown.

Social considerations: Guayule tolerates arid conditions and requires less irrigation than crops that are currently grown in the Southwest. Guayule appears to be more suited to large scale production than production on small farms. Because of the volume involved, the special processing needs, and the fact that natural rubber is a strategic material, guayule may require building new processing plants, which would create new jobs.

Extent of research conducted: Guayule has been used for centuries by native Americans, and by 1910, guayule provided 10 percent of the world's supply of natural rubber. From 1910 to 1946, the United States imported approximately 68 million kg of guayule rubber from Mexico. During World War II, interest in research and development of guayule rubber was high in the United States. However, after the war ended, shipments of *Hevea* rubber from Asia resumed, synthetic rubbers were developed, and interest in guayule was severely dampened.

U.S. interest in guayule was revived in the 1970s, and in 1981, the Department of Defense (DoD) guaranteed a $20 million loan to the Gila River Indian Community (GRIC) to grow several hundred acres of guayule, develop a prototype rubber-processing plant, and develop rubber to be tested. Due to several problems encountered by GRIC, USDA took over the project in 1986. The GRIC continued to grow the guayule, and the Firestone Rubber & Tire Co. was contracted to build an $8.3 million prototype processing plant. The plant was scheduled to begin operations in August of 1989, following a 16-month delay due to solvent leaking into the atmosphere. The pilot-plant size is about 150 ton/yr and will provide rubber for DoD testing and coproduct research. The plant is intended to process 275 acres of guayule into 50 tons of natural rubber, 100 tons of resins and low-molecular-weight rubber, and 1,600 tons of plant residue. There are approximately 300 acres of guayule available for processing, but rubber yields may be low because the plants ideally should be harvested at 3 to 5 years of age and they are now 9 to 10 years old.

Agronomic and breeding research is being conducted at the University of Arizona, University of California-Riverside, Texas A&M University, and New Mexico State University. Coproduct research is being conducted by the Institute of Polymer Science at the University of Southern Mississippi. Investments between 1978 and September 1986 have been about $31.9 million, with the DoD providing $13.1 million, USDA providing $13.2 million, other Federal agencies providing $2.9 million, and the Firestone Tire & Co. providing $2.7 million. Investments for 1987 to 1988 were $19.3 million, with $15 million from DoD and the rest from USDA. Funding for fiscal year 1989 includes $500,000 for breeding and genetics being administered by the ARS, and another $668,000 in Native Latex Grants being administered by CSRS. The Latex Grants are being spent as follows: $240,000 for breeding and genetics research, $160,000 for germplasm collection and research, $150,000 for coproduct research, and $138,000 for unspecified research. It is estimated that about $38 million will need to be spent between 1989 and 1996 to establish a domestic natural rubber industry.

SOURCES: 2,26,28,32,34,46,47

Gumweed

Scientific name: *Grindelia* camporum

Major compounds produced: Diterpene resins, similar to pine resins, can be extracted from the entire plant. The major resin is grindelic acid and its derivatives. Approximately 5 to 18 percent of above-ground dry weight are crude resins with highest concentration in the flowers. After extraction, the bagasse residue is nontoxic and contains 8 to 10 percent protein.

Replacement: Pine resins

Major uses: The resins are used in the naval stores industry (generic name for large class of chemicals including turpentine and wood rosins). Uses for these resins include adhesives, varnishes, and paper sizings. The residue could be used as livestock feed.

Agronomic characteristics: *Grindelia* (a member of the Compositae family) consists of about 195 species of herbs and shrubs native to North and South America. Many of the species are found in the Southwestern United States. Commonly called gumweed, the genus consists of annuals, biennials, and perennials. Gumweed is xerophytic and halophytic. It is most active during hot rainless summer months and can flower and produce two crops in a single growing season. It is probably unsuitable to the cooler climates and shorter growing seasons found in more humid regions of the United States. The species most studied is *Grindelia* camporum, a native of the Central Valley in California. Gumweed needs about 30 in (67.5 cm) of precipitation to produce reasonable yields. Yields in experimental plots have been about 2.2 to 2.5 tons of biomass per acre and up to 5 tons/acre if harvested twice.

Technical considerations: *Grindelia* are naturally outcrossing species and are self-incompatible. Genetic selection for traits in outcrossing species often results in problems of inbreeding depression. With *Grindelia*, it may be possible to increase resin yields, but it would be at the expense of biomass, resulting in a total resin yield that is not significantly higher. Increased yields will be necessary for commercial feasibility, but may be difficult to obtain.

Economic considerations: Currently, U.S. production of rosin is about 600 million pounds. High-quality wood rosin comes from aged pine stumps, but this supply is diminishing. Tapping of live trees to obtain gum rosins is very labor intensive and expensive, and production of gum rosins from this source is declining. Currently, U.S. production of rosins comes mainly from recovery of tall oils, byproducts obtained from the manufacture of chemical wood pulp. It is estimated that U.S. consumption of resins will be 781 million pounds (355 million kg) by the year 1990.

The estimated cost of growing *Grindelia* is about $380 per acre. This includes 30 inches of irrigation, a quantity lower than the requirements of currently grown crops in the production region. If the crop is harvested twice, approximately 5 tons of biomass per acre per year could be achieved. Assuming a double harvest and a processing cost of $35 per ton, the total cost of production is estimated to be $555 per acre. Given a resin content of 10 percent, the break-even cost would be about $0.56 per pound. The current cost of wood rosin is about $0.40 per pound. The cost of the *Grindelia* resin is higher than wood rosin. *Grindelia* resin also is of a lower quality than wood rosin and would have to be further refined to be similar in quality. To achieve economic feasibility, yields will need to be higher, production costs lower, and uses for the bagasse byproduct, perhaps as livestock feed, would be needed.

Social considerations: *Grindelia* tolerates arid conditions and would require less irrigation than crops that are currently grown in the Southwest.

Extent of research conducted: The National Science Foundation funded the collection and evaluation of 10 to 15 species of *Grindelia* from the Southwestern United States. In 1982, a population of 300 plants was started at the University of Arizona's Bioresources Research Facility in Tucson. Private-sector funding from the Diamond-Shamrock Corp. and from Hercules, Inc. has supported product evaluation and development research at the University of Arizona.

SOURCES: 16,25,29,44

Honesty (Money Plant)

Scientific name: *Lunaria* annua

Major compounds produced: The seeds are 30 to 40 percent oil, and contain approximately 48 percent erucic acid, 24 percent C_{24} fatty acids, 18 percent oleic acid, (all monounsaturated) and 10 percent other fatty acids. The meal is high protein.

Replacement: Imported industrial rapeseed.

Major uses: Currently, erucic acid and its derivatives erucamide and behenylamine are used in plastics, foam suppressants, and lubricants. Potentially the oil can be hydrogenated to yield a hard wax, which could be used in cosmetics and candles. Oxidative ozonolysis of erucic acid yields brassylic acid and pelargonic acid. Brassylic acid can be transformed into a liquid wax for use in high-pressure lubricants and industrial paints, and it can be used to make industrial nylons, such as nylon 1313, for use in electrical insulation, automobile parts, and other high-temperature applications. Pelargonic acid can be used in lacquers and plastics. The protein meal could be used as a livestock feed or as an adhesive for plywood.

Agronomic characteristics: Honesty is a member of the Cruciferae family and consists of both annual and biennial varieties. Initiation of flowering requires long daylight hours in the annual varieties and cold winters in the biennials. Seed yield estimates are unavailable.

Technical considerations: This plant is still essentially a wild plant and an extensive breeding effort is needed before commercialization could even be contemplated. The meal contains glucosinolates which have been linked to several physiological problems.

Economic considerations: The potential oil markets are essentially the same as for *Crambe* and winter rapeseed (i.e., 40 million pounds of high-erucic acid oils used to produce primarily erucamide).

Social considerations: It is a perennial that provides ground cover and potential protection against erosion.

Extent of research conducted: Most research to date has been at the Saskatchewan Research Council in Canada.

SOURCES: 21,22,36,46

Jojoba

Scientific name: *Simmondsia* chinensis

Major compounds produced: The seeds contain 45 to 55 percent oil, 95 percent of which is in the form of linear wax esters (fatty acids connected directly to fatty alcohols instead of to glycerol or glycerides). Eighty-seven percent of the fatty acids are of chain length 20 or 22 (eicosanoic acid is C_{20} and docosanoic acid is C_{22}), and there are small quantities of palmitoleic acid (C_{18}) and oleic acid (C_{16}). The fatty acids are monounsaturated. The meal that remains after oil extraction is about 30 percent protein, reasonably high in lysine, and deficient in methionine.

Replacement: Banned sperm oil and possibly petroleum-derived products.

Major uses: Currently, jojoba oil is being used in the cosmetics industry in a variety of uses ranging from shampoos to moisturizers, lipsticks, and shaving creams. It is apparently non-toxic and does not cause eye irritations. Isomerization of jojoba oil yields a soft opaque cream resembling face creams.

Hydrogenation produces a crystalline solid, which has properties resembling beeswax, candelilla, carnauba, and spermaceti, all waxes that are commercially used now. Crystallographically, hydrogenated jojoba oil is similar to polyethylene and can be combined with either polyethylene or polypropylene or both to yield mixed plastics that have lower melting points and are harder than the pure plastic, plus still retain the tensile strength of the pure plastic.

Sulfurized jojoba oil is similar to sulfurized sperm oil and could potentially be used as a high-pressure lubricant. A major difficulty is that it solidifies at temperatures below 50 °F (10 °C) limiting it to high-temperature applications. Before being banned, sperm oil was used to prevent foaming in industrial fermentation processes, such as the production of penicillin G. Jojoba oil also has antifoaming properties and could potentially be used in similar processes. Reactions of jojoba oil with sulfur chloride forms factice, which is used in manufacturing varnishes, adhesives, printing ink, and flooring materials.

Jojoba waxes could possibly be used in floor finishes, coatings, furniture polishes, candles, soaps, crayons, and so forth. The seeds contain tannins that could potentially be extracted and used in the leather industry.

Agronomic characteristics: Jojoba is an evergreen native to the Sonoran Desert region of the Southwestern United States and Mexico. It appears to live at least 40 years. Latitude and day length do not appear to be limiting factors. Jojoba can grow with 8 to 18 inches (20 to 46 cm) of annual precipitation, but for economic production, jojoba should receive 18 to 24 inches (46 to 61 cm) of precipitation, which might require irrigation. It requires porous soil with good drainage and will not tolerate water logging. Jojoba grows in soils ranging from pH 5 to 8 and appears to be tolerant of salinity. In the wild state, jojoba plants are associated with a symbiotic fungus (*Glomus* deserticola) found in the roots. It is thought that this fungus aids in the uptake of phosphorus, zinc, copper, and other elements. Current average seed yields are approximately 200 pounds/acre (224 kg/ha) from 4- to 5-year-old-shrubs, and 3,000 pounds/acre (3,360 kg/ha) from 11- to 12-year-old shrubs. Approximately 2.5 pounds (1.1 kg) of seed are needed to produce 1 pound of oil.

Technical considerations: Jojoba bushes are either male or female and are wind pollinated. However, male and female plants cannot be identified until first flowering, which takes 1 to 4 years. During the first few years, continual removal of male plants and replanting of female plants is needed. This can cause fields to be nonuniform and creates problems with harvesting. Today, most new fields are planted from cuttings or tissue cultures rather than seeds, which helps to reduce or eliminate the problems of identifying males and females. Flowering is triggered by cold or drought stress. A cool fall, followed by a warm wet winter can cause early flowering. If the weather then turns cold (25 °F or lower during the blooming season of January to March), the crop could be lost. Jojoba can tolerate high temperatures (greater than 100 °F), but not prolonged temperatures of below 23 °F. Weed control appears to be more of a problem than pests and diseases, but as more plants are planted over larger geographic areas, some pest and disease problems are beginning to occur. A major cost associated with jojoba is harvesting. Seeds on the same bush do not ripen at the same time requiring multiple harvests. The meal contains simmondsins and tannins which are unpalatable to livestock and potentially toxic. Utilization research performed has been experimental; to be accepted for industrial uses, full-scale utilization research must be performed. Yields need to be improved.

Economic considerations: Currently, the United States plants nearly 42,000 acres to jojoba and produces between 100 to 300 tons of jojoba oil per year. Total U.S exports have been 70 MT in 1985, 134 MT in 1986, and 124 MT in 1987. Japan imports approximately 100 tons and West Germany and the Netherlands together import another 100 tons for use in the cosmetics industry. Value of exports per pound have been steadily decreasing from approximately $8.50 in 1985 to about $6.50 in 1987.

Social considerations: Jojoba grows in arid regions and requires minimal irrigation. Since it is perennial with long payoff times for investment, it may be better suited to large-scale production than small-farm production.

Extent of research conducted: Research on jojoba is conducted at university and ARS labs in the Southwest, particularly the Arid Land Studies at the University of Arizona.

SOURCES: 11,14,29,30,36

Kenaf

Scientific name: *Hibiscus* cannaabinus L.

Major compounds produced: The plant produces a fiber with a cellulose content similar to wood but lower in lignin.

Replacement: Wood pulp

Major uses: Potential uses for kenaf include newsprint, carpet padding, paper for use in stamps, money, magazines, poultry litter, and cardboard. Green, chopped kenaf can be fed as forage.

Agronomic characteristics: Kenaf is an annual, nonwood fiber plant native to east-central Africa. It grows to heights of 12 to 18 feet in approximately 150 days. It can yield between 6 and 10 tons of dry matter per acre. Seed germination requires soil temperatures of at least 55 °F. It is somewhat tolerant of saline conditions. Rainfall of about 5 inches is needed shortly after germination to ensure good growth, but after that, kenaf is relatively tolerant of dry conditions.

Technical considerations: Weeds generally are not considered a problem because of kenaf's rapid emergence and growth; the dense populations needed result in shaded ground conditions. However, favorable conditions are needed to promote this rapid growth, and pre-emergent herbicides may be needed. Kenaf thrives in high temperatures when abundant soil moisture is available, however, it will not tolerate standing water or water-logged soils. The most serious pest kenaf faces is root nematodes. Most kenaf cultivars are photoperiod sensitive and do not flower until day length decreases to about 12.5 hours of light in the fall. Kenaf may require nitrogen, phosphorus, potassium, and calcium inputs. In very dry areas, some irrigation may be needed.

In the Southern Rio Grande Valley, initial experiences indicate that rain-fed kenaf produces about 75 percent of irrigated yields. Research to improve harvesting equipment is needed. Development of uniform size and shape is still needed. Storage needs to be improved. The system envisioned is a cross between that used for wood chips and that used to store bagasse. Because of heat buildup, added attention must be paid to air circulation and/or water cooling.

Major research is still needed to develop products that use kenaf. It has been shown that kenaf can be used to make newsprint. The newsprint made from kenaf is generally whiter and stronger than paper made from wood pulp, and it does not yellow as badly. Kenaf can be converted to pulp under high temperature and pressure. Making newsprint from kenaf requires fewer chemicals and about two-thirds the energy needed to make wood pulp newsprint. Kenaf newsprint uses less ink and does not smudge as much as wood pulp newsprint. Kenaf improves the strength and brightness of recycled paper.

Economic considerations: The United States imports approximately 7 million tons (60 percent of total use) of newsprint a year at a cost of about $4 billion. Constructing this much production capacity would require a large capital investment as it costs approximately $400 million to erect a 600 ton/day capacity plant, which would produce about 0.2 million tons of newsprint per year.

New technologies are opening the way for trees not previously used for newsprint (i.e., aspen and fast-growing eucalyptus) to now be converted to newsprint. Increased recycling of newsprint will require less new wood pulp. Additionally, paper mills are accustomed to working with year-round crops, such as trees, and have large investments in forests. Because of high transportation costs, paper mills generally process material in the immediate area. Utilizing a seasonal crop such as kenaf presents problems. Failure of a kenaf crop could result in high transportation costs to supply adequate processing materials. The potential for crop failure will place a higher priority on storage facilities, which increases the costs of using kenaf.

Kenaf can be used as a supplement to pine for pulp mills already in existence. It is estimated that it will cost approximately $10 million to install equipment needed to utilize kenaf in conjunction with softwood or recycled newsprint pulp at current mills. For kenaf to supply the entire U.S. newsprint market of 12.5 million tons of newsprint per year, approximately 1 million acres would need to be planted to kenaf.

Uses other than newsprint need to be found. Since newsprint represents about 7 to 10 percent of the pulp and paper industry, there are likely many other opportunities that could potentially be developed. In addition to uses as paper and cardboard, kenaf could potentially be used as poultry litter (broiler producers spend about 0.3 cents per pound live weight on litter, and in 1987, poultry production was about 21.5 billion pounds).

Production costs for kenaf average about $20 to $30 per ton, and the cost of harvesting is about $10 to $15 per ton. Currently it is anticipated that farmers will be contracted to grow kenaf and that harvesting will be custom done because of requirements for cleanliness of the product. Kenaf is expected to sell for $50 to $60 per ton. Comparison of estimated returns of kenaf and other crops in Georgia indicate that kenaf (both irrigated and non irrigated production) is expected to have lower net returns than tobacco, cotton, and peanuts (irrigated and nonirrigated) and higher net returns than sorghum, wheat, and oats (irrigated and nonirrigated). Nonirrigated kenaf is expected to have slightly higher net returns than nonirrigated corn, but irrigated kenaf is estimated to have lower net returns than irrigated corn. In the Rio Grande Valley region of Texas, kenaf is more competitive with other crops, particularly the grains. Deficiency payments for cotton decrease the competitiveness of kenaf, but nevertheless, it is felt that the most likely area for initial production of kenaf on a commercial basis will be in Texas.

Social considerations: There is potential for some new mills to be built, particularly if production occurs in Texas, and this has the potential to create new jobs and economic activity in those areas. Kenaf stalks are harvested free of leaves, with the leaves remaining in the field. This could result in 1 to 2 tons of dry leaf matter, which is rich in nitrogen, left on the field. Potentially, 60 to 120 pounds of nitrogen per acre could be returned to the soil in the form of organic matter.

Extent of research conducted: Research on kenaf began in 1956 at the Northern Regional Research Center in Peoria, Illinois (an ARS lab). Over 500 fiber crops were screened, and kenaf was selected as the most promising for further research. In 1978, ARS dropped its research program on kenaf with the hope that private industry would continue the research since it had been shown that newsprint could be made from kenaf.

The American Newspaper Publishers Association did continue some research and began commercial runs of newspapers printed on kenaf paper. The kenaf demonstration project was begun to commercialize kenaf. The ARS and the CSRS in cooperation with Kenaf International, Canadian Pacific Forest Products, and CE Sprout-Bauer Co. joined to form the Joint Kenaf Task Force (JKTF). Phase I of the demonstration project began in 1986 with the USDA providing $141,000 and the JKTF members providing $263,000 for growing, harvesting, fiber handling, pulping, and papermaking trials. Phase II was begun in 1987 and undertook commercial trials. The estimated cost to the JKTF was $644,000, with the USDA providing $300,000 of that support. Phase III is currently underway and involves agricultural research and research to develop additional uses for kenaf.

Congress appropriated $675,000 in funds for fiscal year 1989. The money is being spent as follows: $150,000 each to the ARS labs in Weslaco, Texas, and Lane, Oklahoma; $75,000 to Mississippi State University; $300,000 administered by the CSRS for fiber separation ($200,000), harvest system modification ($20,000), dry-form fruit boxes ($50,000), recycling research ($20,000), and poultry litter research ($10,000 to Texas A&M). The Kenaf Paper Co. of Texas (consisting of Kenaf International, Bechtel Enterprises, Inc., and Sequa Capital Corp.) has begun construction on a $35 million plant in Willacy County, Texas. The plant will handle 84 tons/day, produce approximately 30,000 tons of newsprint annually, and require 4,500 acres of kenaf. The plant is expected to begin full operation is 1991 and to employ about 160 people.

SOURCES: 4,7,9,23,24,29,41,45,46,48,54

Meadowfoam

Scientific name: *Limnanthes* species

Major copounds produced: The seeds are 20 to 30 percent oil, containing 90 percent C_{20} and C_{22} fatty acids, which are primarily monounsaturated. Of the diunsaturated fatty acids, the double bonds are widely separated, which potentially leads to greater stability. The meal is high protein.

Replacement: Products derived from petroleum.

Major uses: Currently, Japan imports the oil for use in cosmetics. Potentially, the oil can be converted to liquid wax esters, which can be used in lubricants. Reacting the oil with sulfur yields factice, a solid chemical rubber. Meadowfoam could potentially be a source of suberic acid, which is currently obtained from castor oil.

Agronomic characteristics: Meadowfoam is native to the Pacific Coast Region of North America. It is planted in the fall and harvested in June or July. Meadowfoam is best suited to mild climates; seed germination occurs in soil temperatures that range between 40 and 60 °F. Some meadowfoam species are insect-pollinated, while others are self-pollinated.

Technical considerations: Self-pollinated meadowfoam species are generally agronomically preferable, however those that have been examined have given lower yields and display less genetic variation than insect-pollinated species. No suitable self-pollinated species have been found, thus attention is focused on insect-pollinated species, such as *Limnanthes* alba, which displays genetic variation for seed retention. Seed shattering is a serious problem with several species. Cool, wet weather may decrease insect activity, decreasing pollination. Yields need to be improved to increase commercial potential.

The major constraint for meadowfoam is the lack of a well-defined market. The fatty acids found in meadowfoam oil are not a replacement for any fatty acids currently being used. Initial tests of use in lubricants have revealed problems of corrosion, foaming, and wear scarring. Extensive utilization research is needed to develop meadowfoam. The meal contains glucosinolates, which causes physiological problems when ingested. The oil is colored and needs to be cleaned, when desired. The lack of a large germplasm collection has limited research.

Economic coniderations: Limited attempts to grow meadowfoam commercially have been made. In 1986 and 1987, approximately 1,000 acres of the meadowfoam variety Mermaid were planted in Oregon. Due to the lack of appropriate processing facilities, the seeds were shipped to Lubbock, Texas, for oil extraction, then shipped to California for export to Japan.

In 1985 to 1986, the Oregon Meadowfoam Growers Association sold 12 tons of oil to Nikko Chemical Ltd. of Japan. An additional 3 tons of oil was shipped to the same company in 1986 to 1987. Croda, Japan, an oil, fats, and chemical supplier has also purchased approximately 3 tons of meadowfoam oil. In February 1989, Croda, Japan received permission from the Japanese Ministry of Health and Welfare to use meadowfoam oil in cosmetics. Toxicology and skin-sensitivity tests have been performed in the United States, and no major problems have thus far been encountered.

Farmers appear unwilling to grow meadowfoam if there is no well-defined market, and manufacturers are unwilling to reformulate their procedures if there is not a consistent high-quality supply. In addition to the amounts of oil exported to Japan, samples have been sent to Canadian firms and the European Economic Community for market development. Currently the Oregon Meadowfoam Growers Association has a 1 year stock of oil and seeds on hand.

Total processing and transportation costs are $0.55 per pound of oil (compared with about $0.03 per pound for soybean oil). Production costs were about $440 per acre.

Social considerations: Different species of *Limnanthes* are adapted to poorer soils and some act as xerophytes and require less water than other grains grown in the same area.

Extent of research conducted: Most of the industrial application research is performed at the Northern Regional Research Center in Peoria. Researchers at Oregon State University are working on varietal improvement and commercial development. The ARS is spending approximately $350,000 on meadowfoam research at Peoria and Oregon State.

SOURCES: 5,22,31,36,43,46

Milkweed

Scientific name: *Ascelepidaceae* genus

Major compounds produced: Latex can be extracted from the whole plant. The latex produced is mainly cardiac glycosides, which are generally cytotoxic and affect the heart, lungs, kidneys, gastrointestinal tract and brain. Nonpolar (hexane) extracts constitute about 4 percent of the above-ground dry weight and consist primarily (85 percent) of triterpenoids and derivatives and 2 percent natural rubber. Polar (methanol) extracts account for about 18 percent of the dry weight and contain primarily sucrose (34 percent), polyphenolics (6 percent) and inositol (5 percent). The remaining residue after extraction contains pectin and is about 16 percent protein. The protein content of the residue is comparable to that of alfalfa, and contains high levels of lysine, but also contains toxic constituents.

Replacement: Petroleum-derived products

Major uses: The latex can be used in glue and chewing gum. The floss fiber can potentially be used to replace goosedown.

Agronomic characteristics: The *Asclepiadaceae* genus contains about 140 species. Most of the species native to North America are perennials, although a few annuals are known. *Asclepias* curassavica is planted as an ornamental plant in semitropical and semiarid regions. *Asclepias* speciosa (showy milkweed) is widely tolerant of habitat and could be grown in the United States in most of the area west of the Mississippi River. It produces more latex than *A.* curassavica.

Technical considerations: A major difficulty with establishing millkweed is that of weed control. During the seedling stage, much energy is devoted to root establishment which aids in drought tolerance but results in the slowly growing, above-ground portion being noncompetitive with faster growing weeds. The average yields of the test plots were about 4.3 MT/ha, but increasing the planting density is expected to increase yields to about 7 to 9 MT/ha. Outdoor, uncovered storage resulted in a significant decrease in methanol (polar) extractable compounds, but the nonpolar (hexane) compounds remained stable. Better storage methods resulted in little loss of either extractable.

Economic considerations: Experimental plots of milkweed, using wild milkweed seed, had variable production costs of $169 per acre ($418 per hectare). Highest expenditures were for weed control. Reduction in the costs of weed control would significantly reduce production costs. In addition, harvesting costs were high, but could potentially be lowered by growing on larger plots to take advantage of economies of scale for machinery. Both pectin and inositol are high-value products produced by milkweed, but extraction and purification is expensive and not commercially competitive at the present time.

Social considerations: Milkweed is itself considered a weed and production may need to be carefully managed to prevent it from becoming a pest.

Extent of research conducted: Native Plants, Inc. conducted some initial research on milkweed, but has discontinued research. The University of Nebraska conducts research on the fiber floss.

SOURCES: 1,52

Rapeseed

Scientific name: *Brassica* napus

Major compounds produced: The seeds are approximately 42 percent oil, of which 45 to 57 percent is erucic acid. The remaining meal is high protein.

Replacement: Imported industrial rapeseed.

Major uses: Currently, erucic acid and its derivatives erucamide and behenylamine are used in plastics, foam suppressants, and lubricants. Potentially, the oil could be hydrogenated to yield a hard wax, which could be used in cosmetics and candles. Oxidative ozonolysis of erucic acid yields brassylic acid and pelargonic acid. Brassylic acid can be transformed into a liquid wax for use in high-pressure lubricants and industrial paints and, can be used to make industrial nylons, such as nylon 1313, for use in electrical insulation, automobile parts, and other high-temperature applications. Pelargonic acid can be used in lacquers and plastics. The protein meal could be used as a livestock feed, or as an adhesive for plywood.

Agronomic characteristics: Rapeseed is a member of the Cruciferae family. It can be grown either as a winter or a spring crop and potentially could be double cropped in the Southeast and southern Midwest regions. Generally, it can be grown anywhere that spring and winter wheat is grown. Rapeseed cannot tolerate extreme cold, and the winter varieties have a restricted planting period. The seedlings must be 2 to 3 inches high before the first frost if they are to survive. Rapeseed does not tolerate poorly drained soils; high rainfall can reduce yields. Expected average commercial yields of winter rapeseed are about 2,000 lbs/acre under dryland conditions and about 3,000 lbs/acre when irrigated. Spring variety yields are about one-half that of the winter varieties.

Technical considerations: Two types of rapeseed can be grown: industrial-quality rapeseed and food-quality rapeseed. Food-quality rapeseed is marketed as Canola oil and generally contains less than 2 percent erucic acid, while industrial-quality rapeseed generally contains at least 40 percent erucic acid. Canola-quality rape and industrial-quality rape cross pollinate resulting in a hybrid that is visually indistinguishable from the parents, but that contains an intermediate level of erucic acid (too high for food uses and too low for industrial uses). Production of the two types of rapeseed must be physically separated. To combat the problem, States such as Washington and Idaho have established rapeseed production districts.

Rapeseed is highly susceptible to flea beetles, cutworms, and various fungi. Asynchronous flowering can result in variable seed maturity, with some mature pods shattering while other pods are still green, causing harvesting difficulties and yield loss. The meal contains glucosinolates and has restricted use as a livestock feed.

Economic considerations: World production of rapeseed oil has increased nearly 35 percent since 1984 (see table C-2, app. C). Most of the rapeseed grown are low erucic acid, low glucosinolate varieties used primarily for edible oil (Canola), however Eastern Europe and Canada produce significant amounts of industrial-quality rapeseed also. The supply appears to be relatively stable due to the large number of producers so that adverse conditions in one country do not necessarily result in a severe supply shock for rapeseed oil. Current U.S. demand for industrial-quality rapeseed (approximately 40 million pounds) is mainly for erucamide and would require an estimated 50,000 acres of domestically produced rapeseed. Development of markets for brassylic acid, such as for the industrial nylon 1313, could increase the demand for high-erucic acid oil sufficiently to require planting of nearly 300,000 acres.

Social considerations: About 3,000 to 8,000 acres of winter rapeseed are annually grown in Idaho. The large increase in imports of rapeseed oil over the last few years is due mainly to increases in Canola-quality and not industrial-quality rapeseed oil (table D-3, app. D). Winter rapeseed provides ground cover over the winter and may decrease soil erosion.

Extent of research conducted: The Office of Critical Materials (OCM) is actively trying to commercialize winter rapeseed. Congress has appropriated $325,000 for fiscal year 1989 to be used for this purpose. Eight States (Missouri, Kansas, New Mexico, Idaho, Iowa, Nebraska, North Dakota, and Illinois) have formed a consortium in cooperation with the OCM to perform research necessary to lead to commercialization. These

States are providing an estimated $2 for every $1 of Federal support for this research.

SOURCES: 19,27,35,36,38,42,46,49,51

Stokes Aster

Scientific name: *Stokesia* laevis

Major compounds produced: The seeds contain 27 to 44 percent oil, with 64 to 79 percent of the oil consisting of vernolic acid, a fatty acid that contains an epoxy group. The meal is high protein.

Replacement: Conversion of oils containing nonepoxy fatty acids, such as soybean, sunflower or linseed, into epoxy fatty acids. Replacement for petroleum-derived epoxy compounds.

Major uses: Currently, epoxy fatty acids are used primarily in the plastics and coatings industries. The epoxy groups of fatty acids act as plasticizers (to provide flexibility) and as stabilizers (by inactivating agents that might cause degradation). In general, the epoxy sites are highly reactive sites where adjacent triglyceride molecules attach to form interlocking polymer networks.

Agronomic characteristics: Stokes aster is a member of the Compositae family. It is a perennial native to the Southeastern U.S. and could potentially be grown in the eastern half of the United States and the Pacific Northwest. Potential seed yield has been estimated to be 1,780 lb/acre (2,000 kg/ha).

Technical considerations: Very little agronomic work has been done on stokes aster, and it is still essentially a wild plant. A well-defined market for epoxy fatty acids exists, but the epoxy fatty acids obtained from stokes aster are not identical to those obtained by conversion of sunflower, linseed, or soybean oil, or those derived from petroleum. Quality control and utilization research is needed.

Economic considerations: Approximately 100 to 180 million pounds of soybean and linseed oil are converted to epoxy fatty acids annually. While the raw material is relatively inexpensive, the chemical transformation of the fatty acids contained in sunflower and soybean oil to epoxy fatty acids is relatively expensive.

Social considerations: As a perennial, stokes aster has potential implications for erosion control.

Extent of research conducted: Apparently little research is being performed on this species.

SOURCES: 20,22,33,36,46

Vernonia

Scientific name: *Vernonia* anthelmintica and *Vernonia* galamensis

Major compounds produced: Seeds from *V.* anthelmintica are 23 to 31 percent oil, 68 to 75 percent of which is vernolic acid, an epoxy fatty acid. Seeds from *V.* galamensis are 42 percent oil containing 72 to 73 percent vernolic acid. Meal from *V.* galamensis contains 42.5 percent crude protein, 10.9 percent crude fiber, and 9.5 percent ash.

Replacement: Conversion of oils containing nonepoxy fatty acids, such as soybean, sunflower, or linseed, into epoxy fatty acids. Replacement for petroleum-derived epoxy compounds. Replacement for organic solvents in paints.

Major uses: Currently epoxy fatty acids are used primarily in the plastics and coatings industries. The epoxy groups of fatty acids act as plasticizers (to provide flexibility) and as stabilizers (by inactivating agents that might cause degradation). In general, the epoxy sites are highly reactive sites where adjacent triglyceride molecules attach to form interlocking polymer networks. Research is being conducted to use *Vernonia* as a diluent for alkyld resin paints.

Agronomic characteristics: *Vernonia* species are members of the Compositae family. *V.* anthelmintica is native to India, and *V.* galamensis is a herbaceous annual from Africa. Attempts to grow *V.* anthelmintica in the United States have thus far been unsuccessful, causing researchers to begin focusing their attention on *V.* galamensis. Yields of *V.* galamensis in Zimbabwe have been as high as 2,290 pounds of seed/acre.

Technical considerations: Seed shattering has been a problem with *Vernonia*, but recently a wild species has been discovered with good seed retention, which may alleviate this problem. Photoperiodism may limit production in temperate regions. Short days are required for flowering, but in colder climates, short days are soon followed by frost, which prevents seed formation. A variety that flowers earlier has been found, so this problem may be overcome. The meal from *Vernonia* species contains antinutritional agents such as vernolepin, which may limit use as a livestock feed. The meal from *V.* anthelmintica was found to be deficient in methionine and lysine and could no be used as livestock feed without additional amino acid supplements. Meal from *V.* galamensis has higher levels of lysine, methionine, and phenylalanine than meal from *V.* anthelmintica, but feeding studies have not been conducted.

Economic considerations: Approximately 100 to 180 million pounds of soybean and linseed oil are converted to epoxy fatty acids annually. While the raw material is relatively inexpensive, the chemical transformation of the fatty acids contained in sunflower and soybean oil to epoxy fatty acids is relatively expensive. About 325 million gallons of alkyld resin paints are used in the United States each year. *Vernonia* oil could be used as diluent in place of organic solvents in these paints. Expected use is one pint of oil per gallon of paint.

Social considerations: *Vernonia* is a potential replacement for industrial uses of soybeans. It could be used to reduce volatile organic compounds resulting from solvents used in paint, with positive impact on air quality.

Extent of research conducted: *Vernonia* was identified by the original USDA/ARS screening in the 1950s. The Northern Regional Research Center has conducted some utilization research. Trial plantings of *Vernonia* were made in Georgia in 1964, but little interest was expressed in developing this species. Recent agronomic research has been conducted in East Africa and the Carribean rather than in the United States. Utilization research is being conducted at the Coatings Research Institute at Eastern Michigan University. The California South Coast Air Quality District, the U.S. Agency for International Development, the State of Michigan, and Paint Research Associates (an industry-financed research group) are providing $425,000 for this research. Some research is also being conducted at Lehigh University.

SOURCES: 8,18,33,36,37

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Appendix B

Selected Industrial Uses for Traditional Crops

Diesel Fuel From Vegetable Oils

Crop: Sunflowers, soybeans, potential new crops such as rapeseed

Major coproducts: Oil, meal, and potentially glycerol

Major uses: The oil can be used as diesel fuel, and the meal as livestock feed. Glycerol is a widely used chemical.

Replacement: Diesel fuel derived from petroleum products. The United States uses approximately 40 billion gallons of diesel fuel yearly, with about 3 billion gallons used for agricultural purposes.

Technical considerations: Chemical and physical composition of the oil determines fuel characteristics. In general, highly unsaturated oils break down faster than saturated oils, but increased saturation leads to solidification at near-room temperatures. Unsaturation is desirable for maintaining liquidity at low temperatures, but undesirable for stability. Ignition quality (cetane number) generally is lower for vegetable oils than for diesel fuels, and vegetable oils have lower heat of combustion. The most serious problem related to using vegetable oils as diesel fuel is their viscosity. Viscosity is critically dependent on temperature, and the viscosity of vegetable oils is more affected by temperature than the viscosity of diesel fuels. The pour points of vegetable oils are also higher than those of diesel fuels, which could create problems in colder climates.

Vegetable oils can be used straight or blended with diesel fuel. Short-term testing of oilseed fuels indicated that these fuels were roughly equivalent to diesel fuel. Fuel consumption was higher because vegetable oils have a lower heat of combustion than diesel fuel. Longer-term tests have had problems of deposit buildup in the combustion chamber and injector nozzle (due to the poor thermal stability of vegetable oils) and piston ring sticking and engine failure (due to decreased fuel atomization and combustion efficiency), particularly in direct-injection diesel engines, the most common type of diesel engine used in the United States. Problems have not been as serious in indirect-injection diesel engines.

Alternatively, vegetable oils can be converted to monoesters, by reacting the oil with alcohol in the presence of a catalyst. Three monoester molecules and a glycerol molecule are obtained from each triglyceride (the process is similar to deriving fatty acids from oils to be used for plastics, soaps, lubricants, etc.). The resulting ester fuels have viscosities similar to those of diesel fuels and also tend to vaporize in a manner more similar to diesel fuel. Short-term tests using methyl esters of rapeseed oil in direct-injection diesel engines appeared not to result in the carbon deposit buildup that occurs with the blends or straight vegetable oils. Using ethyl esters of various degrees of saturation in short-term tests indicated that the unsaturated esters resulted in more coking than the saturated esters. Longer term testing of monoesters derived from soybean oil results in a polymerization and varnish buildup in the cylinder walls. Methyl esters tend to crystallize at 4 to 5° C, requiring storage and transport in heated vessels. Ethyl esters have better low-temperature properties but have higher conversion costs due to water contamination problems.

The land needed to supply enough oil for agricultural diesel use alone could be a constraint. Oilseeds that are high yielding and contain a high percent of oil are preferable. Potential candidates are peanuts (40 to 45 percent oil), cottonseed (18 to 20 percent oil), safflower (30 to 35 percent oil), rapeseed (40 to 45 percent oil), sunflower (35 to 45 percent oil), and soybeans (18 to 20 percent oil). Peanuts and cottonseed are unlikely candidates for economic reasons. Safflower and rapeseed currently are grown only in small quantities; production would need to be greatly expanded. Soybeans and sunflowers are the likely candidates. Average U.S. sunflower yields are about 600 pounds oil per acre, while soybeans yield about 400 pounds per acre. For sunflowers to supplant soybeans as a major oil source, expansion of production is necessary.

Economic considerations: The value of soybeans and sunflowers depends on the value of both the oil and the protein meal produced. The ratio of oil to meal produced, and the percent of the value of the oilseed accounted for by the oil, will in large part determine the supply response of the oilseed to an increased demand for the oil and the economic competitiveness of using that oil for fuel. Soybeans may be self-limiting because more than 60 percent of the value is for the meal. Supplying more soybean oil also results in a greater supply of meal, which decreases the price of the meal. Production will occur up to the point where the increases in oil price offset the decreases in meal prices, unless new markets for meal can be found. These impacts may be more significant for on-farm rather than off-farm processing.

For sunflowers, it is possible to produce enough oil to replace diesel fuel use without producing excessive meal for on-farm livestock use. Unfortunately, sunflower meal is low in lysine and cannot fully supply the protein requirements of livestock, particularly pork and poultry. Farmers would still need to purchase higher-lysine-protein meal, such as soybean meal, or amino acid supplements. This to some extent decreases the attractiveness of on-farm extraction of sunflower seeds. Whether a combination of sunflowers and soybeans is possible is not clear.

The cost of converting sunflower oil to fuel-grade methyl esters is about $1.00 per gallon. A 25 gallon/hour plant can produce fuel-grade sunflower oil-methyl ester for about $3.25 per gallon, a price about three times higher than diesel fuel.

Social considerations: On-farm extraction of oils potentially could have negative impacts on employment, particularly in the oil processing and transportation industries. Increased centralized processing could potentially increase employment in these industries. Total replacement of agricultural uses of diesel fuel would result in small petroleum savings because this market represents about 1 percent of total petroleum use. Conversion of soybeans to fuel uses will decrease agricultural exports unless increased markets for the meal can be found. Edible-vegetable-oil prices will likely increase. Vegetable oils are expected to burn cleaner and cause less air pollution than diesel fuels.

SOURCES: 15,19,24,34

Soybean Uses

Crop: Soybeans

Major coproducts: Oil, flour, and protein

Major uses: The flour is used to make adhesives, mainly for plywood. The oil is used in alkyd paints, as a plasticizer and stabilizer in vinyl plastics, as an antifoamant in fermentation processes, as a carrier for printing ink, as a carrier for agricultural chemicals, and to control grain dust in elevators. The protein is used to make adhesives that bind pigment to paper in the coating process. Historic uses, which are no longer available, include the use of soybean fiber to make blankets, upholstery, and other textiles (marketed as Azlon), and the oil combined with lime and sprayed through an aerator nozzle for extinguishing fires.

Replacement: Petroleum-derived products

Technical considerations: Historically, soybeans have been used for all of the above uses, but have been replaced by petroleum products primarily for economic reasons. Some of the technical problems include a lack of water resistance for the flour adhesives and poor durability, peeling, and scaling of paints, which limits them to indoor use. Today, about 7,000 tons of soy flour and 8,000 tons of soy protein are used to make adhesives. Each year, approximately 120 million pounds of oil are used in the plastics and resins industry and about 40 million pounds of oil are used in the paint and varnish industry.

Soy inks were developed by the American Newspaper Publishers Association in 1985. Soy inks are clear so the pigment shows better and they do not smudge as much as petroleum inks. Newspaper publishers use about 500 million pounds of ink each year which would require approximately 350 million pounds of oil. Approximately one-third of the U.S. newspapers are using soy-based inks for color printing.

Soybean oil used in small volumes (0.02 percent by weight) can be used to suppress dust in grain elevators (up to 99 percent). When compared to untreated grains, use of soybean oil as a dust suppressant does not appear to affect odor, grade, drying characteristics, mold growth, or milling and baking qualities, and there may be some improvement in insect control.

Economic considerations: Food and livestock-feed uses keep the price of soybeans high enough that use for industrial purposes is often precluded. The situation could change if the price of petroleum increases.

Soy oil ink cost 50 to 60 percent more than petroleum-based ink, because more steps are involved in its manufacture (i.e., it costs about 90 cents per pound compared to petroleum-based inks, which cost about 60 cents per pound). For color inks, however, the cost of the color pigments is the major cost, and soy inks have gained in this usage. Also, more papers can be printed per pound of soy ink than convential ink because the color pigments blend better with soy oil than pretroleum-based oil and thus, can be applied in a thinner layer.

SOURCES: 3,5,16,20,28,34,38

Road De-icers

Crop: Corn primarily, but potentially other starch or lignocellulose sources

Major coproducts: Starch, oil, and protein feeds

Major uses: Road deicer

Replacement: Road salt

Technical considerations: Calcium magnesium acetate (CMA) is made by reacting acetic acid with dolomitic limestone. The acetic acid can be obtained by fermentation of corn, however, at present, no large-scale plants exist. The Chevron Co. has marketed CMA. Determination of the optimal bacterial strain for acetic acid production is needed. Approximately 60 bushels of corn are needed to make 1 ton of CMA.

Economic considerations: Acetic acid can be obtained from corn fermentation (or starch or cellulose from other sources) or petroleum sources. Estimates are that using corn priced at $2.80 per bushel would result in production costs of 18 to 19 cents per pound of CMA. This is 7 to 8 times the cost of road salt. CMA bound to sand to increase traction costs about 10 times more than road salt. Utilizing ground corn cobs as the feed stock instead of corn kernels might lower the cost to 12 to 14 cents per pound of CMA. There does not appear to be a significant difference in costs of production utilizing anaerobic (without oxygen) or aerobic bacterial fermentation. It is estimated that an economical size plant would have a capacity of 500 tons/day and a yearly capacity of about 150,000 tons. This size plant would utilize 9 million bushels of corn per year, with 45,000 tons of distillers dried grain as a byproduct. The U.S. uses about 10 million tons of salt per year. Capturing 10 percent of this market would utilize 60 million bushels of corn.

Social considerations: Significant expanded production could increase corn prices, and create dried distillers grains that would compete with soybean meal in the high-protein livestock feed market. A major attraction of CMA is that it has less negative environmental impacts than salt. It is less harmful to animals and the soil than salt, and is 10 times less corrosive. Estimated costs of vehicle corrosion and damage to roads and bridges caused by salt are about $5 billion yearly.

SOURCES: 12,21

Coal Desulfurization

Crop: Corn primarily, but potentially other starch or cellulose sources

Major coproducts: Ethanol, oil, and protein feeds

Major uses: Coal desulfurization

Replacement: Scrubbers and other sulfur removers

Technical considerations: Carbon monoxide and either ethanol or methanol can be used to remove sulfur from coal. One ton of processed coal produces $^1/_2$ barrel of crude oil, 25 pounds of carbonyl sulfide (used in agrichemicals and pharmaceuticals), 35 pounds of hydrogen sulfide (used in pharmaceuticals), 8.3 gallons of acetaldehyde (used to make either acetic acid or acetone), and iron sulfide, which can be burned for heat. Currently, testing at a 1 to 10 pound/hour scale is occurring. The next stage will be to test at the 30 to 100 pound/hour scale and if the procedure continues to look promising, construction of a pilot plant to process 2,000 pound/hour will begin. Funding will be sought from the Clean Coal Technology Program (Department of Energy) for plant construction.

Economic considerations: A 1986 study by the Center for Research on Sulfur in coal estimated the cost of the carbon monoxide ethanol method to be $134 per ton of coal ($5.02 per million Btu). In 1986, the cost of low-sulfur coal was $49.70 per ton. Improvements in technology are needed to significantly lower the cost. The ethanol used could potentially be derived from corn. About 8 gallons of ethanol are required to process one ton of coal (about 3 bushels of corn).

Social considerations: The United States has large deposits of coal, which potentially could be used in place of petroleum. However, much of the coal contains sulfur, which can lead to acid rain when burned. Removing the sulfur is expensive. An economical method to remove sulfur would allow coal to be used in place of petroleum. However, technical difficulties and the fact that ethanol derived from corn fermentation varies greatly in price because of variability in corn and byproduct prices will make widespread use of this technology difficult at the current time. There is also some concern that increased burning of coal will increase carbon dioxide levels.

Research conducted: A joint venture is being conducted by Southern Illinois University-Carbondale (SIU-C), the Illinois State Geological Survey (ISGS), the Univeristy of North Dakota Energy and Environmental Research Center, Ohio University, and Eastern Illinois University. Funding is provided by the Illinois and Ohio Corn Marketing Boards, ISGS, SIU-C, the Illinois Department of Energy and Natural Resources, and the U.S. Department of Energy.

SOURCES: 21,45

Super Absorbants

Crop: Corn

Major coproducts: Cornstarch which has been modified to absorb up to 1,000 times its weight in moisture, oil, and protein feeds.

Major uses: These modified starches are currently used in disposable diapers (about 200 million pounds/year) and as a burn treatment. They are also being used in fuel filters to remove water. They could also be used as a seed coating to increase germination, as an agricultural chemical delivery system, and as a soil conditioner.

Technical considerations: As a soil conditioner, corn starch polymers bind soil particles into stable aggregates, which results in better aeration and increased water penetration and retention. There are two types of polymers used: 1) hydrogels and 2) water-soluble linear polymers. Hydrogels are polymers crosslinked to adjacent molecules so that the structure is insoluble in water. They act like a sponge, absorbing 50 to 400 times their weight in water and delivering 40 to 95 percent of the water to plant roots. They increase the water-holding capacity of sandy soils and reduce frequency of irrigation. Soil moisture supply is more constant. Water-soluble linear polymers are large chains of repeating units. They do not hold water. Rather, they bind soil particles together to form lattices and as such maintain soil in a loose and friable state. The bound soil particles are stable in water. There is less evaporative loss because the top layer of polymer-treated soils acts like a mulch. Besides corn starch, guar polysaccharides and lignin can be used to make the polymers.

Modified corn starch can be used as an encapsulating agent for active ingredients such as herbicides. The advantages of encapsulation are: 1) extension of activity, 2) reduction of evaporative and degradative loss, 3) reduction of leaching, and 4) decrease in the dermal toxicity of the active agent. Encapsulation involves dispersing the starch in aqueous alkali followed by crosslinking reactions after the active agent has been interspersed. Corn starch can be used as an entrapment agent for both solid and liquid active agents. The efficiency of encapsulation and rate of release of active agents depends on starch type, temperature and concentration of starch during gelatinization, amount of active agent incorporated, and method of drying. Preliminary data indicates that herbicides encapsulated in corn starch are less mobile in soil and could potentially reduce the possibilities of groundwater pollution. One technical goal is the elimination of chemicals used to form the matrix because these chemicals prohibit using many encapsulated products for food or livestock feed.

Economic considerations: Byproducts of corn grown for starch compete with soybeans in the livestock feed market. Price for the starch-based products will fluctuate with the price of corn and the value of these feed byproducts.

Social considerations: There is some potential to decrease groundwater contamination by using encapsulated pesticides. Livestock feed byproducts will compete with soybeans.

Research conducted: Northern Regional Research Center in Peoria, Ill.

SOURCES: 6,18,41,43

Ethanol

Crop: Corn primarily, but potentially other starch or lignocellulose sources

Major coproducts: Two production methods are utilized: dry-mill and wet-mill corn processing. In dry-mill processing, the corn is ground, slurried with water, and cooked. Enzymes convert the starch to sugar, and yeast ferments the sugars to a beer that contains water, alcohol, and dissolved solids. The solids are dried and sold as dried distillers grain (a livestock feed). The remaining beer is distilled and dehydrated to form anhydrous ethanol, with CO_2 as a byproduct. One bushel of corn produces approximately 2.5 to 2.6 gallons of ethanol and 18 pounds of dried distillers grain.

In wet-mill processing, corn kernels are soaked in water and sulfur dioxide, and the portions of the corn kernel other than the starch are removed. These portions are used to make corn oil, corn gluten feed (20 to 21 percent crude protein) and corn gluten meal (60 percent crude protein), which can be used as high-protein livestock feeds. The almost pure starch that is left is converted to sugar, then fermented and distilled to produce ethanol and CO_2. Because the wet-mill production process is identical to the process used to produce high-fructose corn syrup through the starch phase, the two operations can be combined in the same plant, resulting in a significant production cost saving. One bushel of corn produces 2.5 to 2.6 gallons of ethanol, 2.5 pounds of gluten meal, 12.5 pounds of gluten feed and 1.6 pounds of corn oil. In 1985, approximately 60 percent of the nearly 800 million gallons of ethanol produced came from wet-mill plants.

Major uses: Either as a fuel, a fuel extender, or as an octane enhancer.

Replacement: Gasoline

Technical considerations: Vehicle problems have been encountered with ethanol/gasoline blends. Altering the volatility level is required to prevent warm-weather stalling. First-time use in older cars can result in fuel filter clogging because ethanol is a solvent that dissolves built-up gums and deposits already in the system. Blends might separate in the presence of water. Use is not recommended for vehicles left idle for long periods such as recreational vehicles. Most automobiles have now been adjusted to minimize such problems.

Ethanol production needs to be improved. In the near term, three new technologies show promise: 1) replacement of yeast with *Zymomonous* mobilis bacteria, 2) membrane separation of solubles, and 3) yeast immobilization. Z. mobilis ferments faster than yeast, and tolerates a greater temperature range. It also has a higher selectivity for producing ethanol and gives greater yields. Membrane separation of solids reduces energy requirements by removing as much as 40 percent of the water prior to boiling. Membrane clogging is a problem. Immobilization allows the sugar or starch solution to be passed over the enzymes, bacteria, or yeast. Use of the enzymes and yeast is maximized, and contamination concerns are reduced by eliminating yeast recycling. Immobilization is applicable only to wet-milling because it requires a clarified substrate.

If ethanol production is to be increased significantly, feedstocks other than corn will be needed. Alternatives are high-starch or cellulosic biomass. Potential cellulosic candidates include forage crops (e.g., alfalfa stems or fescue), crop residues (e.g., corn stalks), or municipal wastes (e.g., wood chips or sugar beet pulp). Attempts are being made to identify microorganisms that convert wood hemicellulose into high yields of sugar and alpha cellulose. New processes that increase the efficiency of converting cellulose to sugars are being developed.

Economic considerations: Large plants (annual capacities of 100 to 150 million gallons) are able to capture economies of scale in both the production and marketing of the fuel. Small plants (0.5 to 10 million gallons annually) can be profitable under conditions such as: 1) location in areas of limited local grain production and high transportation costs to major grain markets, 2) joint location with food processing or other industrial facilities where fermentable wastes are produced, or 3) location near a feedlot where byproducts can be fed directly to livestock without drying.

Costs of ethanol production are highly variable because of fluctuating prices for corn and byproducts. Feedstock costs (the net of the price paid for the corn and the credit received for selling the byproducts) have ranged from $0.10 to $0.79 per gallon of ethanol in recent years. Other cash operating expenses, such as labor, energy, and administration, have ranged from $0.35 to $0.65 per gallon of ethanol depending on the size of the plant. Energy costs average about 36 percent of the cash operating expenses. Investment costs to build an ethanol plant range from $1.00 to $2.50 per gallon of installed capacity. Construction of a new dry-mill plant with 40-million-gallon annual capacity is about $2.00 to $2.50 per gallon capacity. Adding ethanol production capacity to a wet mill already producing high-fructose corn syrup costs about $1.00 to $1.50 per gallon capacity. It is estimated that the capital charge per gallon of ethanol produced is $0.19 to $0.48. For a stand alone (ethanol production only) plant, total production costs (feedstock costs, cash operating costs, and capital costs) have ranged from a low of $0.75 per gallon (in a year with exceptionally high byproduct prices) to an average of $1.40 to $1.50 per gallon. Ethanol production at high-fructose corn syrup production plants can reduce production costs by as much as $0.20 per gallon.

Currently, gasoline/ethanol blends (required minimum of 10 percent ethanol) are exempted from 6 of the 9 cents Federal excise tax on gasoline, which is equivalent to a 60 cent per gallon subsidy for ethanol. Additionally, 28 states offer state fuel tax exemptions or producer subsidies which average 20 to 30 cents/gallon. Using corn priced at $2.00 per bushel, and maintaining Federal subsidies, ethanol is competitive with petroleum at $22 to $24 per barrel in plants using the average technology available, at $20 per barrel in new state-of-the-art wet-processing mills, and at $13 per barrel at extensions of high-fructose corn syrup mills. Removal of the Federal excise tax exemption and corn prices of $2.50 per bushel implies that petroleum prices of about $40 per barrel are needed for ethanol to be price competitive with gasoline.

Ethanol yields from cellulosic biomass have been increased from about 40 gallon/ton of biomass to 60 gallon/ton. Approximate cost is $1.50 to $2.00 per gallon. Wood used for energy is both lower valued and more expensive to harvest because harvesting operations are geared to removing large logs. Improvements in harvesting would lower costs. Collecting agricultural residues is also expensive. Municipal wastes may offer the best feedstock source. Currently, ethanol production from cellulose is more expensive than corn but could be competitive with corn at corn prices in the $3.50 to $4.00 per bushel range.

Methyl tertiary butyl ether (MTBE) competes with ethanol as an octane enhancer. Currently, MTBE sells for about $0.70 per gallon. Ethanol sells for $1.20 per gallon, but because of the 60 cents per gallon Federal subsidy, ethanol is less expensive than MTBE. MTBE production costs are sensitive to the price of methanol and butanes. Most production expansion is likely to occur in oil-producing regions, which can take advantage of low-cost methanol supplies. Refiners who have already committed to internal production of MTBE are likely to continue using it rather than ethanol. Use of ethanol is further discouraged by the need to physically separate it from gasoline to prevent phase separation. Independent fuel distributors who do not use pipelines for fuel transport and who must purchase high-octane blending agents are likely to be the primary customers of ethanol for octane enhancement. Passage of the Clean Air Act which mandates use of oxygenates to reduce pollution in some cities may enhance the position of ethanol relative to MTBE.

Increased production of ethanol affects the corn market, the oilseed market, and potentially the livestock and other grains markets. Ethanol production raises corn prices and decreases the price of soybean meal because of the high quantity of gluten feeds produced as a byproduct of ethanol production. Falling soybean prices and rising corn prices cause a shift of acreage from soybean to corn production, particularly in the Corn Belt. It is unlikely that livestock production will be significantly affected unless ethanol production exceeds 3 billion gallons annually because increased corn prices would be offset by decreased protein-supplement prices. Above 3 billion gallons, lower byproduct-feed prices would possibly result in increased beef production. Large-scale expansion of ethanol production is unlikely unless exemption from federal excise taxes are guaranteed at least through the year 2000 (the exemption is due to expire in September 1993). Without the continuation of the exemption, ethanol production is not expected to exceed 1.1 billion gallons. With the exemption continued through 2000, ethanol production could expand to a level of 2.7 billion gallons by 1995, which would trigger higher corn prices and use an additional 800 million bushels of corn. Increased production of protein byproducts would require finding export markets if the byproducts are to maintain their value. Passage of the Clean Air Act is expected to create additional incentives for the use and expanded production of ethanol.

Social considerations: Environmental concerns have renewed interest in alternative fuels. The Clean Air Act mandates that states implement plans to control emissions when concentrations of lead, sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide, and particulate matter exceed standards. Many of these pollutants are found in motor vehicle emissions. Because ethanol contains oxygen, addition of ethanol to gasoline increases the air-to-fuel ratio, and carbon monoxide and hydrocarbon emissions are decreased. Nitrogen oxide emission levels increase. Addition of ethanol to gasoline increases fuel volatility and thus increases the emission levels of volatile organic compounds, which in the presence of sunlight form ozone. MTBE also reduces carbon monoxide without increasing fuel volatility.

Significant changes in aggregate farm income for grain producers as a result of market price changes is unlikely to occur because of the impact of the commodity support programs. For corn producers, ethanol production would need to increase to the 3 to 4 billion gallon range by 1995 to exceed corn target prices if they remain at current levels. Large increases in ethanol production would benefit corn producers, and possibly other grain producers, but harm soybean producers. Because of differences in regional production patterns, there could be significant interregional impacts. The Corn Belt could gain, and the Delta Region and Southeast could lose.

A U.S. Department of Agriculture Economic Research Service study found that if commodity programs in the 1990 farm bill remain similar to those in the 1985 Food Security Act and the Federal excise tax exemption is extended through the year 2000, then expanding ethanol production to the 2.7 billion gallon level would result in Federal commodity program savings exceeding federal ethanol subsidies through 1994. After that, ethanol subsidies exceed farm program savings. Furthermore, by the year 2000, the cumulative cost of the ethanol subsidies exceeds the cumulative savings of the commodity programs.

Estimates are that production of 3 billion gallons of ethanol would increase direct employment by 3,000 to 9,000 jobs. No estimate was made for indirect employment impacts or for employment that may be lost in other sectors of the economy.

SOURCES: 2,10,12,13,22,36,39,40,46

Degradable Plastics

Crop: Corn primarily, but other starch or cellulose sources are possible
Major products: Starch, oil, and protein feeds
Major uses: Degradable plastics
Replacement: Nondegradable plastics
Technical considerations: First generation degradable plastics are generally of two types; photodegradable and/or biodegradable. Photodegradable plastics degrade in the presence of ultraviolet light and are produced by adding photosensitive agents (e.g., photosensitive transition-metal salts or organometallic compounds) or by forming copolymers with photosynthetic groups (e.g., carbonyl groups). Photodegradable six-pack rings, films, and bags are commercially available.

Biodegradable plastics are designed to degrade in the presence of microorganisms. The most common method used incorporates starch and usually some autooxidants (i.e., compounds that form free radicals that accelerate polymer chain break down) into the plastic. Early products generally contained about 7 percent starch because this was the maximum loading many plastic polymers could handle without processing or equipment changes. Newer methods are using higher starch levels. The U.S. Department of Agriculture has, for instance, developed a method that mixes dry starch or starch derivatives with dry synthetic plastic, water, sodium hydroxide, and urea. Plastics containing as much as 50 percent cornstarch can be made, but durability decreases. Biodegradable plastic bags and agricultural mulches are commercially available.

Another possible approach is the formation of starch (or lignin or cellulose) copolymers with plastics. Radiation or chemicals can be used to generate free radicals (reactive sites) on the starch molecule. These free radical sites are then reacted with a polymerizable monomer (a building block for plastics), which is then polymerized. Alternatively, in place of using free radicals, a third polymer compatible with both the synthetic plastic and the lignin, starch, or cellulose is used. This third polymer links to each of the other two polymers to form a stable bond. The physical properties of these copolymers, particularly water solubility, depend on the nature of the synthetic plastic used. Hydrophilic polymers, such as polyacrylamide, will disperse in water. Hydrophobic polymers, such as polystyrene, will not. This method offers flexibility as to the types of plastics that can be made.

The approaches described above to produce biodegradable plastics all use some combination of biological and petroleum based polymers. Second generation biodegradable plastics are being developed that utilize biological polymers (i.e., starch, cellulose, lactic acid, etc). Under certain conditions, starch can be combined with water to create a compound that is somewhat similar to crystalline polystyrene, and that disintegrates in water. Lactic acid-based biodegradable plastics are being produced from raw materials such as potato and cheese wastes. The bacteria *Alicaligenes* eutrophus can use organic acids and sugar as a feedstock to produce poly(hydroxybutyrate-hydro-xyvalerate) polymers (PHBV) which can be injection molded and made into films with conventional plastic processing equipment. Other bacteria such as *Klebsiella* pneumoniae convert glycerol (potentially derived from vegetable oils) into acrolein which can be used to make acrylic plastics.

A major constraint to the acceptance of degradable plastics is the lack of a clear definition of degradability. It is not known under what conditions these plastics degrade and what is contained in the residues left behind. USDA is testing degradability of blended plastics and beginning to develop assays to measure degradability. The special strains of bacteria developed for the assays were able to degrade the starch in the blends within 20 to 30 days. However, after 60 days, the plastic part of the blends was intact. The plastic films used did not visually appear different, but pits where the starch had been were found on electron microscope scans. The plastic films had lost tensile strength and were susceptible to mechanical breakup. For films that will be used as agricultural mulches and then plowed under the ground, this type of degradation might be acceptable. For many other uses, it may not be. Additionally, tests performed in soil showed that the rate of degradation varied substantially among different soil types.

Starch/plastic blends containing less than 30 percent starch degrade slowly. Some studies have shown that a threshold value exists at 59 percent starch loading. Below 59 percent, only 16 percent of the starch particles are accessible to each other; above 59 percent loading, 77 percent of the starch particles are accessible to each other which greatly accelerates degradation. Most commercial degradable starch/plastic blends contain about 6 percent starch. Enzyme digestion tests carried out in controlled experiments on cellulose/polymer grafts resulted in the cellulose in the grafts being degraded faster than cellulose alone.

Economic considerations: Some degradable plastics are currently on the market. Most of these products are photodegradable six-pack yokes. Some starch blends are used as lawn bags and agricultural mulches. Estimates are that on average, they cost 5 to 15 percent more than convential plastic products.

Estimated manufacturing costs for some of the degradable plastics are high. For example, manufacture of plastics with the *A*. eutrophus bacteria currently costs about $15 per pound, but expanded production is expected to lower to cost, possibly to half this level. This compares to about $0.65 per pound for conventional plastics. The starch-based polymer plastics are expected to sell at $2.20 per pound.

Because many of the degradable plastics utilize cornstarch, there is potential to increase demand for corn. The intended use for many of the degradable plastics is in packaging, since the life span of these products is very short. U.S. consumption of plastics for packaging is expected to reach 18.8 billion pounds by 1992. As a rough approximation of how replacement of these plastics with degradable plastics might affect corn demand, assume that the entire volume of packaging plastics is replaced by a 50 percent starch-plastic blend. The amount of corn needed to supply the starch is approximately 4 percent of the annual average production of corn. The economic analysis for such an increase would be similar to that for corn ethanol since both ethanol and degradable plastics utilize the starch portion of the grain. In both cases, coproducts produced would be corn gluten meal and corn gluten feed, which would compete with soybean meal in the high-protein livestock feed markets. As with ethanol, production costs of starch blends will depend somewhat on the price of corn and the value of the corn products.

This analysis however, assumes that corn starch will be the natural polymer of choice in natural polymer/synthetic polymer blends and/or grafts. Other natural polymers can be used such as cellulose and lignin. Both could be derived from corn stalks. However, both can also be derived from the paper and pulp manufacturing industry. As an example, the United States paper industry produces 33 million MT of Kraft lignin each year, which is primarily used for fuel, silage, or compost. Water-soluble graft copolymers can be made from this lignin. Potentially, these copolymers could be used in a variety of ways, including degradable plastics.

Social considerations: Each year the United States produces about 320 billion pounds of municipal solid waste, of which 7 percent (by weight) and 18 percent (by volume) are plastics. In 1987, 55 billion pounds of plastic were produced and 22 billion pounds were discarded. More than half of the plastics discarded are in the form of packaging. Plastics are among the fastest growing components of municipal waste.

Utilizing degradable plastics is one tool in dealing with the large amounts of municipal waste produced in the United States each year. But by itself, it is not going to be enough. Other solutions will need to be found also. Some environmentalists are concerned about degradable plastics because of the lack of knowledge about the residues that remain after degradation. Additionally, there is concern that degradable plastics will adversely affect attempts to increase the recycling of plastics. Degradable plastics mixed with nondegradable plastics during recycling could contaminate the recycled plastic product. A major use envisioned for degradable plastics is in the food packaging arena. However, the Food and Drug Administration has not approved such use. Degradable plastics with high starch contents under appropriate conditions become moldy. Premature partial degradation might expose food to harmful organisms. Leaching of chemicals from the plastic might also occur. Considerable research is needed to determine the safety of degradable plastics for food uses.

Extent of research conducted: The General Accounting Office evaluated the extent of Federal support for degradable plastic research for 1988. A total of $1,729,000 supported 12 projects. The sources of funding were the Department of Agriculture ($941,000 for 4 projects), Department of Defense ($575,000 for 4 projects), Department of Energy ($150,000 for 3 projects) and National Science Foundation ($63,000 for 1 project). The USDA projects are developing degradable plastics utilizing corn starch and testing degradable plastics already available. DOD research is supporting research on bacterial production of plastics and degradable plastics that can be used for marine waste disposal. The DOE is supporting research mainly on cellulose and lignin copolymers and somewhat on starch copolymers. The NSF is supporting research on lignin copolymers.

Research on lactic acid-based plastics is being conducted at Battelle Memorial Institute (Columbus, OH) and Argonne (IL) National Laboratory. Research using *K.* pneumoniae and vegetable oils is being conducted at Northern Regional Research Laboratory (Peoria, IL). Researchers at MIT, Univ. of Massachusetts, Office of Naval Research, Michigan State University, and University of Virginia are also working on developing biopolymers. Japan and Europe also have programs to produced biopolymers.

In addition to federally supported research, several private firms are interested in degradable plastics. Some already have products on the market. Some examples, by no means exhaustive, are:

1. Rhone-Poulenc, Ecoplastics, Princeton Polymer Laboratories, Du Pont, Union Carbide, Dow Chemicals, Mobil Chemicals, First Brands, Webster Industries, and SunBag all produce photodegradable additives and products.
2. Archer Daniels Midland, St. Lawrence Starch, Ampacet, AgriTech, Amko Plastics, Beresford Packaging, Polytech, and Webster Industries make starch-based masterbatch and products.
3. The Warner Lambert Company is producing starch-based polymers.
4. Montedison is producing thermoplastic starch resins that are alloys of cornstarch and synthetic resins.
5. ICI Biological Products is producing PHBV polymers.

SOURCES: 4,7,8,9,11,14,21,25,26,29,30,31,32,33,35,36,42,44

Biomass As a Chemical Feedstock Source

Crop: Corn primarily, but other starch and cellulose sources are possible

Major coproducts: Starch, oil, and gluten meal

Major uses: The starch is used to make commodity chemicals, the oil is used for edible purposes, and the gluten meal is used as livestock feed.

Replacement: Commodity chemicals derived from petroleum

Technical considerations: Technically, it is possible to produce fuel and most commodity chemicals from biomass (organic material produced by photosynthesis). Development of biomass as a source of fuel is impeded by: 1) the size of the United States fuel industry, 2) low energy content, 3) seasonality, and 4) the dispersed geographic locations of biomass. Use of biomass for commodity-chemical production would require fewer biomass resources and not put as much pressure on food sources. As an example, production of a typical commodity chemical at the rate of 0.5 million metric ton/year would require less than 1 percent of the United States corn crop. Thus, it seems reasonable to expect the greatest potential for biomass conversion to be for commodity-chemical production. Glucose is the primary starting material, obtained from starch derived from crops or lignocellulose found in woody and fibrous plants. The glucose can be converted via chemical transformations into a variety of commodity chemicals. Starch is easier to work with but competes more directly with food uses for plants. Crops that could serve as a starch source include corn, cassava, and buffalo gourd (a potential new crop). Lignocellulose is more difficult to hydrolyze to sugars but may be more available in larger quantities. Potentially it could be produced on land less suitable for good production and therefore not compete as strongly with food uses.

Economic considerations: The major constraint is economics. The petrochemical industry is highly integrated with multiple byproducts being used to produce other chemicals. In addition, large economies of scale allow for the relatively inexpensive production of fuel and many commodity chemicals. Some major commodity chemicals used in the United States will probably continue to be produced from petrochemical sources for some time. One example is ethylene. Production of ethylene from starch is complex and more expensive than cracking petroleum. Additionally, it is a large market. It is estimated that to provide 100 percent of the yearly ethylene market from starch derived from corn would require 50 percent of the corn crop. Producing ethylene, and similarly propylene, from starch seems impractical.

Chemicals other than ethylene and propylene may, however, have potential. Possibilities include ethanol, acetic acid, acetone, isopropanol, n-butanol, methyl ethyl ketone, and tetrahydrofuran. These chemicals are used in the production of other compounds. With some reduction in price, they might be competitive with petrochemical sources. Improvements in conversion efficiencies are needed. Other likely candidates are those chemicals that contain oxygen, since starch and glucose both contain about 50 percent oxygen. Possibilities include sorbitol used in the food processing industry, citric acid used in detergents, lactic acid used in thermoplastics and possibly biodegradable plastics.

The ability of biomass to compete with petroleum as a chemical feedstock hinges on rising petroleum prices.

As long as petroleum is fairly cheap, biomass will not be economically attractive. In addition, coal gasification and natural gas conversion can also be used to produce many of the same chemicals as biomass or petroleum cracking. Currently, natural gas is simply flared off as a waste product in petroleum drilling and processing in the Middle East. Potentially this could be used to manufacture chemical feedstocks. The United States is rich in coal. This coal is a more geographically concentrated resource than biomass. It is unlikely that as large a capital investment will be needed to fit processed coal into petroleum feedstock schemes as would be necessary for biomass. Additionally, many U.S. oil companies already have large investments in coal reserves. Environmental questions could have an impact on use of coal as a chemical feedstock. Land-use patterns and subsequent environmental impacts will be important if biomass is used to produce fuel and commodity chemicals.

Social considerations: Reasons given for using biomass to produce commodity chemicals include sustained production in many parts of the world, smaller and more geographically dispersed production facilities, conservation of nonrenewable resources, and the potential to use wastes that would otherwise need disposal.

Extent of research conducted: The Tennessee Valley Authority, in cooperation with the Department of Energy, conducts research to convert lignocellulose to chemicals.

SOURCES: 1,4,6,18,23,27,37,46

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Appendix C

Selected New Food Crops and Other Industrial Products

Table C-1—Selected Potential New Food Crops

Grains	Beans	Fruits	Tubers	Vegetables
Amaranth	Adzuki	Atemoya	Cassava	Canola oil
Blue corn	Black turtle	Carombola	Cocoyam	Chayote
Quinoa	Chickpeas	Lingonberry	Groundnut	Jimaca
Triticale	Edible soybeans	Mayhaw	Sweet potato	Tomatillo
White lupin	Mung	Papaya	Taro	
Wild rice		Persimmon		

SOURCE: Office of Technology Assessment, 1991.

Biopharmaceuticals

U.S. research on plants as sources of medicinals appears to be limited. Most major drug companies and the National Cancer Institute have either reduced or eliminated plant screening for drug potential. One successful plant-derived drug is anticancer alkaloids found in the Madagascar periwinkle by Eli Lilly & Co. (9). The National Cancer Institute is currently interested in testing taxol recovered from the bark of the Pacific yew for anticancer activity (5).

Difficulties in screening and characterizing compounds have impeded research on biopharmaceuticals. It may be cheaper to synthesize the simple compounds than to extract and purify them from plants. Highly complex compounds are more difficult to synthesize, and in these cases plant extraction might be competitive. Cell culturing is another alternative (9).

The United States does import plant-derived pharmaceuticals, including cinchona bark (quinine), belladonna, coca leaves, and opium for medicinal use. Additionally, the United States exports some plants that are used as medicines in other countries. Ginseng (*Panax* ginseng) is an example. It grows wild in deciduous hardwood forests and is cultivated, with 90 percent of the domestic production in Marathon County, Wisconsin. Average per-acre yields are 3 tons of green ginseng root, which dries to about 1 ton. Ginseng is risky to produce, highly susceptible to fungi, and takes 6 to 7 years to mature. Planting costs, seedbed preparation, weeding, and harvesting cost nearly $20,000 per acre. Prices of cultivated ginseng have averaged around $50 per pound (1980-83) (3).

Potential medicinal plants include *Coleus* barbatus, a perennial from India. The diterpene forskolin, currently used in research and potentially a hypertensive, has been isolated from the root tubers. Attempts to grow this plant in Michigan have been successful, but quality is highly variable (10).

Biopesticides

Currently, plant-derived insecticides and synthetic analogs are available for use. Some examples include pyrethrum, rotenone, nicotine, and hellebore. Pyrethrum is obtained from flowers grown in Kenya, Tanzania, and Ecuador. Synthetic analogs, which are more stable and effective in the field, have replaced much of the use of pyrethrum. Rotenone comes from roots of *Leguminosae* species and is used to control animal ectoparasites and in home and garden uses. Nicotine is not widely used because of high production costs, toxicity and limited effectiveness (2). Powder from the roots of hellebore are used to kill lice and caterpillars. Other plants suggested as potential producers of insecticides include:

1. Sweetflag (*Acorus* calamus), a semiaquatic perennial that can be grown on dry land. An American variety grows in the Southeastern United States. Essential oils obtained from the roots of European and Indian varieties produce B-asarone and asarylaldehyde, which attract and sterilize fruit flies, and can be used as a fumigant for stored grains (4).
2. Big sagebrush (*Artemesia* tridentata), a perennial that grows in the deserts of the Western United States. Active ingredients include the antifeedant deacetoxymatricarin, which acts against the Colorado potato beetle among other insects (4).
3. *Heliopsis* longipes, a perennial herb native to Mexico. Active ingredients are found in the root and include affinin which acts against mosquitoes and houseflies (4).
4. Mamey apple (*Mammea* americana), a tree native to the West Indies and which can be grown in Florida. The principal active ingredients are mammein and its derivatives, which are obtained in the seeds and fruit pulp. It can be used against fleas, ticks, and lice (4).

5. Sweet basil (*Ocimum* basilicum), currently used as an herb or spice and easily grown in the United States. The oil contains many compounds that are active against the larva of mites, aphids, and mosquitoes (4).
6. Mexican marigold (*Tagetes* minuta), an annual native to South America which can be grown in the United States. Active ingredients include 5-ocimenone and a-terthienyl, which are found in many parts of the plant and act as nematocides to kill mosquito larvae. Approximately 50 to 60 percent of the oil is tagetone, which acts as a juvenilizing hormone (4).
7. Neem (*Azadirachta* indica), a tree native to India. It thrives in hot dry areas and is salt tolerant. It is easy to care for and fruits in about 5 years. One tree can produce 30 to 50 kg of seeds per year. Thirty kg of seeds yield about 6 kg of oil and 24 kg of meal. Active ingredients include azadirachtin contained in the seed oil, which acts as a growth regulator and feeding deterrent against many beetles. Neem is a broad-spectrum insecticide; only small amounts of the active ingredients are required. Research on neem is being conducted at the USDA Horticulture Research Station in Miami. Recently, the horticulture products division of WR Grace & Co. acquired trademarks and patents for the technology used to produce insecticides from neem and will market an insecticide under the name of Margosan-O (1,4,6,7).

To be commercially viable, an insecticide needs to be effective against a wide range of insects.

Active ingredients derived from plants could also be used as herbicides. A potential plant with herbicidal properties is Dyer's Woad (*Isates* tinctoria). This plant grows in the Western United States. The seed pods contain a chemical that is toxic to the roots of grasses (8).

Appendix C References

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Appendix D
Miscellaneous Commodity Statistics

Table D-1—Calculations of Acreage Requirements

General formula used:

(Import levels) x (percent of fatty acid)[a] + (new crop yields/acre) x (percent of oil) x (percent of fatty acid)[a] = acres of new crop needed

Imported crops	Import levels[b,c]	Percent of fatty acid[d]	New crops	Yield/ acre[e,f]	Percent of oil[d]	Percent of fatty acids[d]
Coconut oil	1,120	45 Lauric	*Cuphea*	1,500	30	80 Lauric
Palm kernel oil	403	50 Lauric	*Lesquerella*	1,500	25	65 Hydroxy
Castor oil	94	85 Hydroxy	Stokes Aster	1,500	35	70 Epoxy
Soybean oil	180	Converted to epoxy	*Vernonia*	1,500	25	70 Epoxy
Rapeseed oil	191	50 Erucic	*Crambe*	1,500	40	55 Erucic
Hevea rubber	1,790		Rapeseed	2,000	40	50 Erucic
Newsprint	7		Guayule	500		
			Kenaf	7		

NOTE: See table 5-2.

[a] Where applicable; [b] Newsprint imports in million tons (1987 levels); [c] Oil and rubber imports in million lbs (1987 levels); [d] Assumed average values; [e] Oilseed and guayule yields in lbs per acre (assumed values); [f] Kenaf yields in tons per acre (assumed values).

Table D-2—World Production of Major Oils (million MT)

	1984-85	1985-86	1986-87	1987-88[a]
Coconut oil	2.63	3.32	2.99	2.64
Linseed	0.64	0.59	0.61	0.63
Palm kernel oil	0.96	1.11	1.09	1.14
Palm oil	6.92	8.17	8.09	8.57
Rapeseed	5.60	6.18	6.80	7.48
Soybean	13.34	13.77	15.07	15.35
Sunflower	6.17	6.63	6.47	7.03
Tallow	6.52	6.40	6.39	6.23

[a] Data for 1987-88 is preliminary.

SOURCE: U.S. Department of Agriculture, *Agricultural Statistics 1988* (Washington, DC: U.S. Government Printing Office, 1988).

Table D-3—Rapeseed Production in Selected Countries (1,000 MT)

Country	1976-78	1984	1985	1986
Canada	2,102	3,228	3,508	3,809
North Europe[a]	119	771	990	1,033
West Europe[b]	298	2,892	3,026	2,517
East Europe[c]	447	1,526	1,668	1,955
China	1,462	4,205	5,607	5,870
India	1,712	2,608	3,073	2,636

[a] North Europe includes Sweden, Denmark, and Finland.

[b] West Europe includes France, United Kingdom, and West Germany.

[c] East Europe includes Czechoslovakia, East Germany, and Poland.

SOURCE: U.S. Department of Agriculture, Economic Research Service, "World Indices of Agricultural and Food Production, 1977-86," Statistical Bulletin No. 759, March 1988.

Table D-4—U.S. Vegetable Oil Imports

Oil	Quantity (MT)			Major supplier
	1985	1986	1987	
Castor	37,189	37,664	42,528	Brazil
Coconut	450,199	548,317	506,387	Philippines
Olive	43,959	54,010	63,736	Italy
Palm	225,410	279,597	187,899	Malaysia
Palm kernel	128,310	195,963	182,951	Malaysia
Rape	15,332	55,293	87,317	Canada, East Europe
Tung	6,939	5,575	5,895	Argentina

SOURCE: U.S. Department of Agriculture, Economic Research Service, Commodity Economics Division, "Foreign Agricultural Trade of the United States," Calendar Year 1987 Supplement, June 1988.

Table D-5—1987 U.S. Wax Imports[a]

Wax	Quantity(MT)	Dollar/MT	Dollar/lb
Beeswax	832	2,798	1.27
Candelilla wax	352	2,054	0.93
Carnauba wax	4,015	1,854	0.84

[a] The data is the price paid to the exporter, not the wholesale price and does not include costs of shipping, insurance, etc.

SOURCE: U.S. Department of Agriculture, Economic Research Service, Commodity Economics Division, "Foreign Agricultural Trade of the United States," Calendar Year 1987 Supplement, June 1988.

Table D-6—U.S. Imports of Guar Seeds

Year	Quantity (MT)	Value ($1,000)
1985	804	83
1986	301	25
1987	12	4

SOURCE: U.S. Department of Agriculture, Economic Research Service, Commodity Economics Division, "Foreign Agricultural Trade of the United States," Calendar Year 1987 Supplement, June 1988.

Table D-7—U.S. Imports of Rubber, 1986-87

Year	Quantity (MT)	Value ($1,000)
1986	777,577	612,060
1987	813,871	741,498

Note that the value does not include cost of shipping, insurance, etc.

SOURCE: U.S. Department of Agriculture, Economic Research Service, Commodity Economics Division, "Foreign Agricultural Trade of the United States," Calendar Year 1987 Supplement, June 1988.

Table D-8—Wholesale Prices of Major Oils

Oil source	Fatty acid	Dollar/lb[a]	Range[b]
Castor oil	Ricinoleic acid	0.39	0.33-0.73
Coconut	Lauric acid	0.23	0.16-0.60
Linseed	C^{18} acids	0.25	0.25-0.33
Palm	Palmitric/Lauric acid	0.17	0.14-0.33
Rapeseed	Erucic acid	0.64	0.55-0.64
Soybean	Linoleic acid	0.15	0.15-0.31
Sunflower	Linoleic acid	0.16	0.16-0.34
Tallow	Stearic Acid	0.15	0.09-0.15
Tung	Multiunsaturated acids	0.53	0.39-1.19

[a] 1987 wholesale price per pound.

[b] Range in wholesale price per pound, 1983-87.

SOURCE: U.S. Department of Agriculture, *Agricultural Statistics 1988* (Washington, DC: U.S. Government Printing Office, 1988)

Table D-9—Oil Content of U.S. Oilseed Crops

Oilseed crop	Percent oil
Cottonseed	18-20
Peanut	45-50
Rapeseed	40-45
Safflower	30-35
Soybean	18-20
Sunflower	35-45

SOURCE: Everett H. Pryde, "Chemicals and Fuels From Commercial Oilseed Crops," *Fuels and Chemicals From Oilseeds: Technology and Policy Options*, American Association for the Advancement of Science Selected Symposia Series No. 91, Eugene B. Shultz, Jr. and Robert P. Morgan (eds.) (Boulder, CO: Westview Press, Inc., 1984), pp. 51-69.

Table D-10—1987 Harvested Acreage and Value of Major U.S. Crops

Crop	Acreage (millions of acres)	Vaule (billions of dollars)
Barley	10	0.9
Corn	65	12.1
Oats	7	0.6
Sorghum	10	1.1
Soybeans	56	10.4
Wheat	56	5.3

SOURCE: U.S. Department of Agriculture, *Agricultural Statistics 1988* (Washington, DC: U.S. Government Printing Office, 1988).

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the workshop participants. The workshop participants do not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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